Mohlman.

The Activated Sludge Method Of Sewage Treatment.

# THE ACTIVATED SLUDGE METHOD OF SEWAGE TREATMENT

BY

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THESIS

Submitted in Partial Fulfillment of the Requirements for the

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May 9th 1916

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Floyd William Mohlman

ENTITLED The Activated Sludge Method of Sewage Treatment

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Doctor of Philosophy

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# THE ACTIVATED SLUDGE METHOD OF SEWAGE TREATMENT

## INTRODUCTION

The Nuisance Removal Act, passed by the British Parliament in 1855, at the close of a severe cholera epidemic, marks the beginning of the science of the chemistry and biology of sewage. This was the first appreciation of the necessity for treating sewage in such a manner as to render it non-putrescible.

Since 1855 innumberable theories have been advanced, and many processes have been tried but the ideal process has not yet been found. Plants which were among the first constructed, and plants representing all processes having any merit at all are still in use.

Disposal by dilution in streams was the earliest method, and is still in most general use in the United States. In 1915* 83 per cent of the 41,800,000 people in the United States who were connected with sewerage systems discharged raw sewage into water courses, lakes or the ocean.

Broad irrigation is one of the older methods, and is still in use at the sewage farms of Paris and Berlin. The immense amount of land required has prevented extensive adoption of this

* Metcalf and Eddy. Disposal of Sewage, p. 240.

practice.

Chemical precipitation has been used extensively. In this process, the sewage is treated with lime, lime and iron, alum, or a combination of the precipitants named and the precipitate formed is allowed to settle. This process is still in use, but it's use is limited because of the large amounts of comparatively worthless sludge produced, and because of the necessity of further treatment to obtain complete purification.

When septic tanks were invented it was thought that the most satisfactory solution of the sewage disposal problem had been found. The septic tank is still in quite general use in the United States but the early claims that all organic matter would be destroyed have not been substantiated. While some of the solid organic matter applied in the sewage is liquefied and gasified, at times sludge is discharged in the effluent. The tanks require occasional cleaning, the sludge is not worth recovery as a fertilizer and the odor from such tanks is usually very bad. Purification by this process is not complete, and if it is used in conjunction with further treatment, and septic action is carried too far, complete purification of the sewage is prevented.

While until recently the septic tank has been considered the most satisfactory preliminary treatment, it has been supplanted in new installations by the Imhoff tank. The special advantage which the Imhoff tank has over the septic tank is due to its two-story construction by which the settling solids and the

gases of fermentation are separated from the incoming sewage. This tank is open to the same objection as the septic tank with respect to the production of large amounts of valueless sludge.

For the final treatment of sewage, some means of oxidation is necessary. The intermittent sand filter was the first type to be used successfully in America, and under certain conditions this is still a very satisfactory method of treatment. The great objection to sand filters is the excessive amount of land required and the expense of construction when sand of the proper quality is not procurable, which practically eliminates them from consideration in the case of large cities. They require preliminary treatment of the sewage, with the resultant production of worthless sludge.

The contact filter, which has been used to some extent, has fallen into disuse because of the variable degree of purification effected, and because frequent cleaning and careful attention are required. Preliminary treatment is also necessary with contact filters.

The sprinkling filter is most widely used at the present day, and yet it has disadvantages. It requires a great deal of land, and immense quantities of crushed stone for its construction. The effluent is of variable quality, and contains considerable suspended matter, which must be removed in secondary settling basins. Odors are sometimes very pronounced and a very great objection is the presence of myriads of flies, gnats and bugs over the filters. The usual production of almost valueless

sludge is unavoidable.

At the present day, Imhoff tanks for preliminary treatment and sprinkling filters for final treatment are usually recommended. In all the methods mentioned the disposal of the sludge is the greatest problem. Because of the small amount of fertilizing elements, it is practically worthless, and often entails considerable expense for its disposal. The situation is comparable to that which exists in gold mining, where millions of dollars worth of gold is present in tailings from which the metal cannot be recovered profitably. Millions of dollars worth of nitrogen and phosphorus are present in sewage, only awaiting some process by which they may be recovered profitably. With the propaganda of conservation of our resources being pushed so actively at the present time, this by-product of our modern civilization should not be overlooked. Any process which will recover these elements profitably must surely be ranked as one of the greatest discoveries of this century. The process of purifying sewage by aeration in the presence of activated sludge promises to recover this nitrogen and phosphorus profitably, as well as to compete from the standpoint of purification, with any present methods.

## HISTORICAL

All forms of final disposal of sewage are aeration processes. Aerobic decomposition of the unstable organic matter is necessary in order to obtain stable conditions. Dilution in streams accomplishes this by means of the dissolved oxygen present in the water. All of the present forms of sewage filtration are aeration processes. The oxygen of the air is the essential agency through which sand filters, contact filters and sprinkling filters operate. Naturally, long ago, forced aeration of sewage was tried, but without practical success.

The earliest attempts to oxidize sewage by aeration were made by Dupre and Dibdin* on London sewage, and by Dr. Drown**

*Royal commission on Sewage Disposal, 1884, Vol. 2
**Eng. Record. Feb. 7, 1914. p. 158.

on the sewage of Lawrence, Massachusetts. They found that oxidation accomplished in this way was a very slow process, and not at all practical.

Waring* attempted unsuccessfully to apply air on a working

*Rafter and Baker, Sewage Disposal in the U.S., 1894, p.535.

scale.

In 1892 Mason* and Hine conducted experiments on the

*Journal, American Chemical Society, Vol., 14, p. 7.

oxidation of sewage by means of aeration. They concluded

that air had but little oxidizing effect on sewage.

In 1897 Fowler* confirmed their conclusions.

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*5th Annual Report, 1897, Rivers Depart., Manchester Corporation

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After these discouraging experiments, aeration was not again attempted until 1911 when Black and Phelps* studied the

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*The Discharge of Sewage into New York Harbor. 1911. p. 64-78

---

possibility of aerating the sewage of New York City. They aerated sewage in tanks filled with inclined wooden gratings for varying periods up to twenty-four hours. The oxidation was so slight that the usual nitrogen determinations showed practically no purification. Some measure of purification was indicated by incubator tests, and Black and Phelps recommended that the process be adopted on a larger scale, but it was not adopted.

Clark, Gage, and Adams* had often tried aeration of

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*Annual Report, Miss. State Board of Health, 1913 (75), 288-304.

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sewage at the Lawrence Experiment Station, but had been unable to obtain satisfactory results until 1912. In that year they were able to nitrify sewage successfully by aeration for twenty-four hours in a tank containing slabs of slate about one inch apart, covered with a zoögleal mass of colloidal matter deposited from sewage. The effluent required further treatment, however, and it was not claimed that this treatment would obviate filtration.

Gilbert J. Fowler* of Manchester, England, had tried

*Journal Society Chemical Industry, Vol. 31, No. 10, 1912.

aeration with some modifications on English sewages, but had obtained only indifferent results. Upon his return to England after a visit to Lawrence in 1912, he renewed his work on aeration, and on April 3, 1914, his assistants, Messrs Ardern and Lockett reported* the astonishing results which they had

*J. Soc. Chem. Ind. Vol. 33, p. 523-39

obtained.

In their first experiment, Ardern and Lockett aerated samples of Manchester raw sewage, contained in gallon bottles, until complete nitrification ensued; the aeration was effected by means of an ordinary filter pump.

About five weeks aeration was required in order to obtain complete nitrification. At the end of this period the clear oxidized liquid was removed by decantation, a fresh sample of raw sewage was added to the deposited sludge and aeration was continued until the sewage was again completely nitrified. This procedure was repeated a number of times with the retention in each case of the deposited solids. As the amount of deposited solids increased, the time required for complete nitrification decreased, until eventually raw sewage was completely nitrified in from six to nine hours.

Ardern and Lockett called this sludge, which induced such

active nitrification, "activated sludge", and this name has been generally accepted and used to designate the process.

In August 1914, Dr. Edward Bartow saw the work in progress at Manchester, and upon his return to this country, suggested that experiments with activated sludge be started at the University of Illinois. The first aeration experiment was started on November 2, 1914.

## EXPERIMENTAL

Sewage has been aerated

I. In bottles of three gallons' capacity.

II. In a laboratory tank 9 1/2 inches square and 4 feet, 6 inches deep, having a capacity of 16 gallons.

III. In four concrete tanks 3 feet, 2 inches square and 8 feet, 5 inches deep, each having a capacity of 600 gallons.

### I. BOTTLE EXPERIMENTS

The first experiments were conducted in three gallon bottles. The sewage was collected as needed from the main outfall sewer of Champaign at Wright and Healy streets. This is the point where the sewer leaves the city. The sewage is strong, fresh, sanitary sewage containing no industrial wastes.

Aeration of Sewage without Sludge.

A gallon of this sewage, collected at 9 a.m. on November 2, 1914, was aerated until completely nitrified. Compressed air taken from the University supply was blown into the sewage through glass tubes. No measurement of the air was made. This process was repeated with different samples of sewage in order to study the course of the reaction when no activated sludge was present.

The ammonia nitrogen decreases, at first gradually, eventually very rapidly. The nitrite nitrogen increases in proportion to the decrease of ammonia nitrogen. After the nitrite nitrogen has reached a maximum and the ammonia nitrogen is practically

gone, there is a relatively sudden change of nitrite into nitrate nitrogen. (Table I, Fig. I.) The complete aeration of sewage in four different experiments has given similar results.

<u>Aeration of Sewage with Activated Sludge</u>.

Activated sludge was built up in the manner suggested by Ardern and Lockett*. The results of the individual treatments are too exhaustive to be included in this thesis, but the general results may be summarized.

*J. Soc. Chem. Ind. Vol. 33. p. 523-39

The time required for nitrification decreased very rapidly as the sludge accumulated. On the seventh treatment nitrification was complete in 12 1/2 hours.

On the thirtieth treatment, with about 33 per cent of sludge, the time required for complete nitrification was between four and five hours. The course of the reaction is very different from that which takes place when no activated sludge is present. The ammonia nitrogen decreases rapidly, nitrate nitrogen increases as ammonia nitrogen decreases, and nitrite nitrogen never reaches a very high amount. (Table II, Fig. II). In several series of nitrite determinations, made at short intervals during a number of aerations with activated sludge, the nitrite values never reached a very high amount. (Table III) The reactions with and without activated sludge differ greatly. (Compare Table I and Fig. I, Table II and Fig. II).

The nitrification in both cases follows the nitrogen cycle, that is, nitrogenous organic matter is oxidized to

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TABLE I.

AERATION OF SEWAGE

No Activated Sludge Present

Air Distribution through Glass Tube.

| Date | | Time days | Nitrogen Parts per million Ammonia. | Alb. Ammonia. | Nitrite. | Nitrate. |
|---|---|---|---|---|---|---|
| Dec. | 18 | 0 | 38.00 | 5.20 | .07 | .37 |
| " | 19 | 1 | 30.00 | 4.20 | .02 | .38 |
| " | 21 | 3 | 28.80 | 4.00 | .11 | .45 |
| " | 28 | 10 | 22.00 | 3.60 | 5.00 | .20 |
| " | 29 | 11 | 8.00 | 2.60 | 16.00 | .40 |
| " | 30 | 12 | 1.60 | 2.40 | 23.00 | 1.00 |
| " | 31 | 13 | .36 | 1.88 | 28.00 | 2.00 |
| Jan. | 1 | 14 | .16 | 1.48 | 31.00 | 1.00 |
| " | 2 | 15 | ---- | ---- | 33.00 | ---- |
| " | 4 | 17 | ---- | ---- | 33.00 | ---- |
| " | 5 | 18 | ---- | ---- | 30.00 | ---- |
| " | 6 | 19 | .28 | 1.92 | 27.00 | 5.00 |
| " | 7 | 20 | .44 | 1.84 | 14.00 | 18.00 |
| " | 8 | 21 | .28 | 1.68 | .30 | 31.70 |
| " | 9 | 22 | .24 | 1.60 | .05 | 31.95 |

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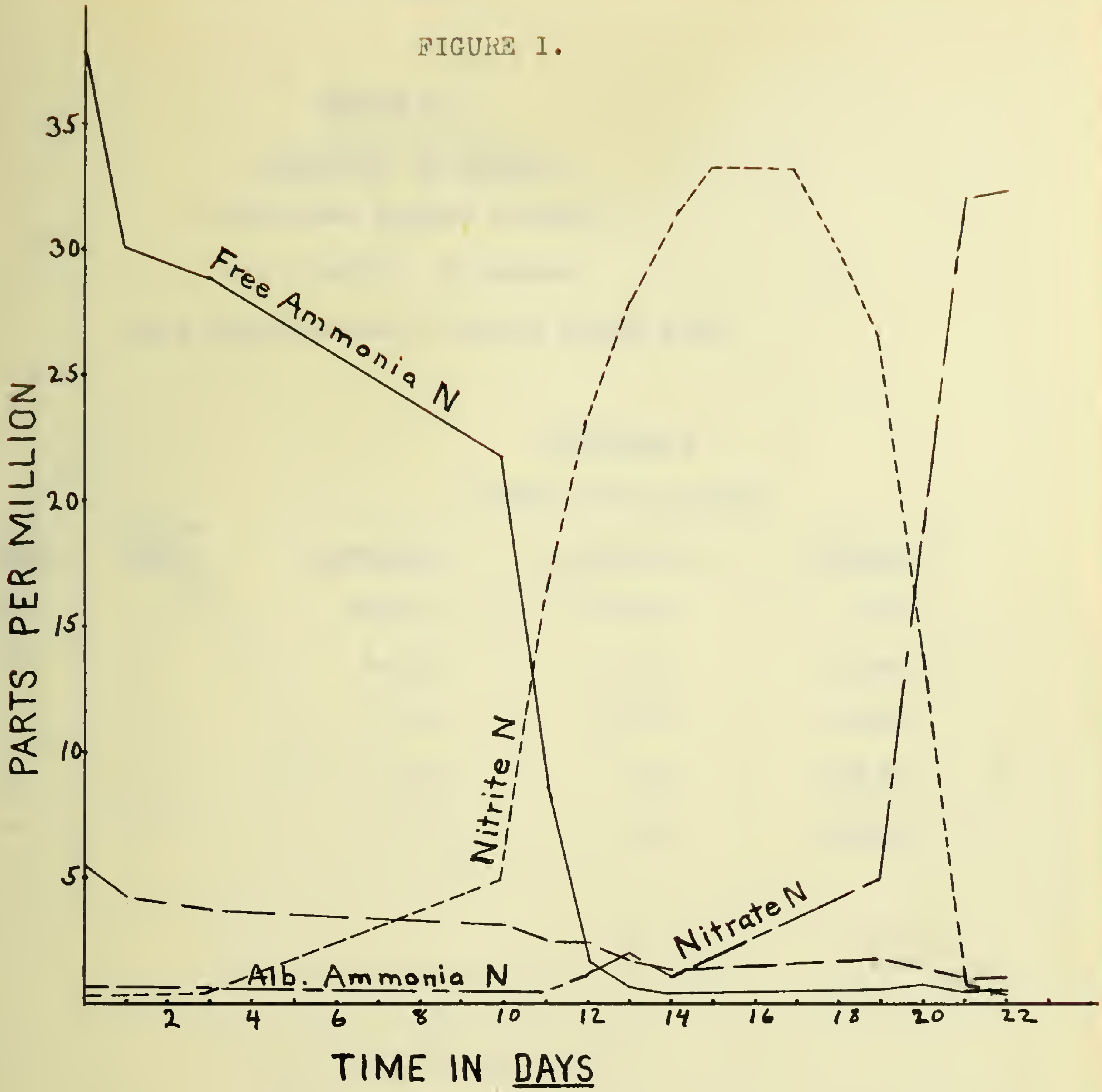
FIGURE I.




Aeration of sewage.

No activated sludge present.

Air distribution through glass tube.

TABLE II.

AERATION OF SEWAGE

Activated Sludge Present

1 sludge: 3 sewage

Air Distribution through Glass Tube.

| Date | Hours Time | Nitrogen Parts per million Ammonia | Nitrite | Nitrate |
|---|---|---|---|---|
| Feb. 6 | 0 | 22.00 | 1.80 | 2.80 |
| " " | 2 | 9.00 | 6.00 | 10.40 |
| " " | 4 | .18 | 4.00 | 16.80 |
| " " | 6 | .20 | .10 | 23.90 |
| " " | 8 | .18 | .10 | 23.90 |

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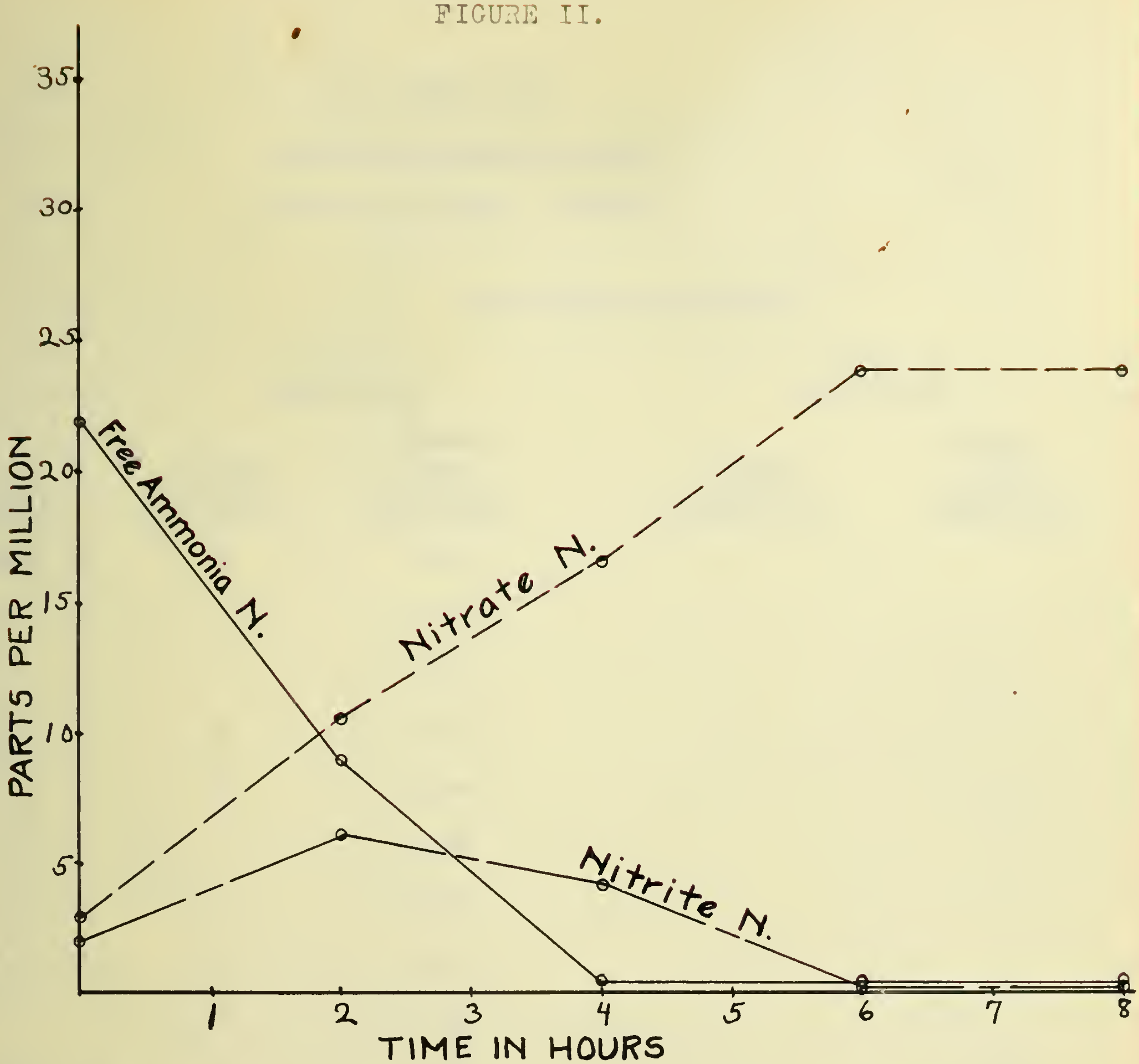
FIGURE II.




Aeration of sewage.

Activated sludge present.

1 sludge : 3 sewage.

Air distribution through glass tube.

## TABLE III

## NITRITE INVESTIGATION

Activated Sludge Present.

Nitrogen as Nitrite

| | Series A. | | Series B | |
|---|---|---|---|---|
| Date | Hours Aeration | Parts per million | Hours Aeration | Parts per Million |
| Jan. 9 | 0 | .18 | | |
| " " | 2 | .01 | | |
| " " | 4 | .00 | | |
| " " | 6 | .20 | | |
| " " | 8 | .43 | | |
| " " | 9 | 1.25 | | |
| " " | 10 | 3.00 | | |
| " " | 11 | .40 | | |
| " " | 13 | .10 | | |
| Jan. 11 | 0 | .00 | 0 | .00 |
| " " | 1 | .00 | 1 | .00 |
| " " | 2 | .00 | 2 | .00 |
| " " | 3 | .01 | 3 | .10 |
| " " | 5 | .02 | 5 | 4.00 |
| " " | 6 | .02 | 6 | 4.50 |
| " " | 7 | .10 | 7 | 6.50 |
| " " | 12 | .05 | 12 | .30 |
| " " | 24 | .00 | 24 | .15 |

TABLE III. (concluded)

| Date | Series A Hours Aeration | Series A Parts per Million | Series B Hours Aeration | Series B Parts per Million |
|---|---|---|---|---|
| Jan. 16 | 0 | .30 | 0 | .30 |
| " " | 1 | .55 | 1 | .00 |
| " " | 2 | 1.60 | 2 | .30 |
| " " | 3 | 3.60 | 3 | 1.65 |
| " " | 5 | 6.60 | 5 | 3.60 |
| " " | 1 hour settling | | 1 hour settling. | |
| " " | 5 | 6.40 | 5 | 3.20 |
| " " | 6 | 6.00 | 6 | 3.40 |
| " " | 6 | 7.60 | 6 | 3.60 |
| " " | 7 | 8.40 | 7 | 3.60 |
| " " | 9 | 8.60 | 9 | 8.00 |
| " " | 24 | .15 | 24 | .20 |
| Jan. 18. | 0 | .00 | 0 | .00 |
| " " | 1 | .00 | 1 | .00 |
| " " | 3 | .10 | 3 | .05 |
| " " | 4 | .40 | 4 | .15 |
| " " | 6 | 1.00 | 6 | .25 |
| " " | 1 hour settling | | 1 hour settling | |
| " " | 8 | 1.50 | 8 | .25 |
| " " | 9 | 2.40 | 9 | .20 |
| " " | 10 | 1.70 | 10 | .15 |
| " " | 11 | .70 | 11 | .10 |
| " " | 20 | .05 | 20 | .05 |
| Jan. 20 | 0 | .00 | 0 | .00 |
| " " | 9 | 3.80 | 9 | 8.00 |
| " " | 10 | 4.00 | 10 | 7.40 |
| " " | 11 | 4.50 | 11 | 7.60 |
| " " | 12 | 3.90 | 12 | 5.40 |
| " " | 13 | .10 | 13 | .20 |
| " " | 14 | .10 | 14 | .10 |

ammonia nitrogen, to nitrite nitrogen, to nitrate nitrogen. In aeration of sewage without sludge the last two stages are quite distinct, but in the presence of activated sludge, the formation of nitrites is immediately followed by their conversion into nitrates. In other words the speed of the reaction

Nitrites + O = Nitrates

is nearly equal to that of

Ammonia + O = Nitrites.

Since the oxidation is biological, this would seem to show the presence of great numbers of nitrite and nitrate-forming bacteria in the activated sludge. These forms have been isolated from the sludge.*

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*Russell, R., Biological Studies of Sewage Purification, Thesis for M.S., U. of I., 1915, p. 35.

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These experiments indicated the theory of the action of activated sludge, as follows:

The oxidation of the organic matter of sewage is accomplished by biological agencies. Therefore, two things are essential for the oxidation, air and bacteria. The bacteria must be of the proper type, that is, nitrifying forms. The reaction is

Ammonia nitrogen + Nitrifying bacteria + Air = Nitrates

In the aeration of sewage without sludge, the nitrifying forms are very few in number, because conditions have been unfavorable for their presence and growth. In some cases the sewage is entirely anaerobic, which means practically the elimination of

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all nitrifiers. With the few nitrifying bacteria present, the complete nitrification of sewage without sludge must take place slowly.

With the accumulation of activated sludge, and by the maintenance of continuous aerobic conditions there are optimum conditions for the growth of nitrosomonas and nitrobacter. These bacteria increase enormously, and the time necessary for complete nitrification is greatly shortened.

The above theory may explain the acceleration of nitrification but other features of the process, clarification and bacterial reduction, are explainable in another way.

The clarifying efficiency of activated sludge is remarkable, as most of the effluents are as clear and attractive as drinking water, with no trace of colloidal matter present. This feature must undoubtedly be due to the adsorptive power of the sludge acting in conjunction with the "scrubbing" effect of the air. The sludge has a spongy, flocculent appearance, and the efficient removal of colloidal matter must in a large part be due to this nature of the sludge. The sludge also, evidently acts about the same as a chemically precipitated floc in removing bacteria. Russell* has shown that an average of 95%

*Russell, R., loc. cit., p. 15.

of the bacteria are removed in 4 hours aeration with 25% of sludge.

T. Chalkley Hatton,* who has conducted extensive experiments with activated sludge at Milwaukee, reports 97% removal

* Eng. News, July 15, 1915, p. 135.

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of bacteria in 3-1/2 hours with 25% of sludge.

To prove whether or not the action of enzymes assists in clarification and bacterial removal 25% of clarified effluent was added to raw sewage. No clarification other than that which could be ascribed only to dilution resulted. It is not likely that enzymes are of much assistance in clarification.

## II. LABORATORY TANK EXPERIMENTS

The bottle experiments just described yielded valuable data concerning certain chemical and biological features of the process, but it was realized that the volume treated was small, the air distribution poor, and that the process as a whole was not conducted efficiently. In order to treat larger volumes of sewage, to get a better distribution of air, and to measure the air, a new apparatus was built.

### Description of Apparatus.

A tall wooden box, 9 inches square and 5 feet deep, was fitted with plate glass front and back to permit easy observance of the air distribution and the condition of the sewage and sludge. A porous plate 1-1/2 inches thick and 9 inches square, of a patented material called "Filtros" was placed four inches above the bottom of the tank. "Filtros" is made of carefully graded quartz sand mixed with ground glass; when heated the glass fuses and binds the mixture firmly together. Air passes through the plate freely and in fine bubbles.

An inlet for air, and an outlet, for water which might filter through the plate, opened into the space below the plate. Compressed air from the University supply was used. The air was

measured through an ordinary gas meter. A siphon was used to remove the supernatant liquid after settling of the sludge. Experiments were carried on at room temperature. A photograph of this tank is shown on page 21, (Fig. III).

Building Up of Sludge.

The diffusion of the air through the plate reduced the time required for complete nitrification of the first sewage treated to 15 days, (Table IV, Fig. IV). 4,830 cubic feet of air were required for the 16 gallons of sewage in the tank.

TABLE IV

AERATION OF SEWAGE

No activated sludge present

Uniform distribution of air through porous plate.

| | | Nitrogen Parts per million | | | |
|---|---|---|---|---|---|
| Date | Time Days | Ammonia | Alb.Ammonia | Nitrite | Nitrate |
| Jan 4 | 0 | 36.00 | 6.60 | .01 | .71 |
| " 7 | 3 | 34.00 | 3.40 | 1.20 | .60 |
| " 11 | 7 | 0.40 | 3.00 | 32.00 | 2.00 |
| " 18 | 14 | 0.60 | 2.60 | 7.50 | 18.50 |
| " 19 | 15 | 0.80 | 2.20 | .10 | 25.90 |

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FIG: III

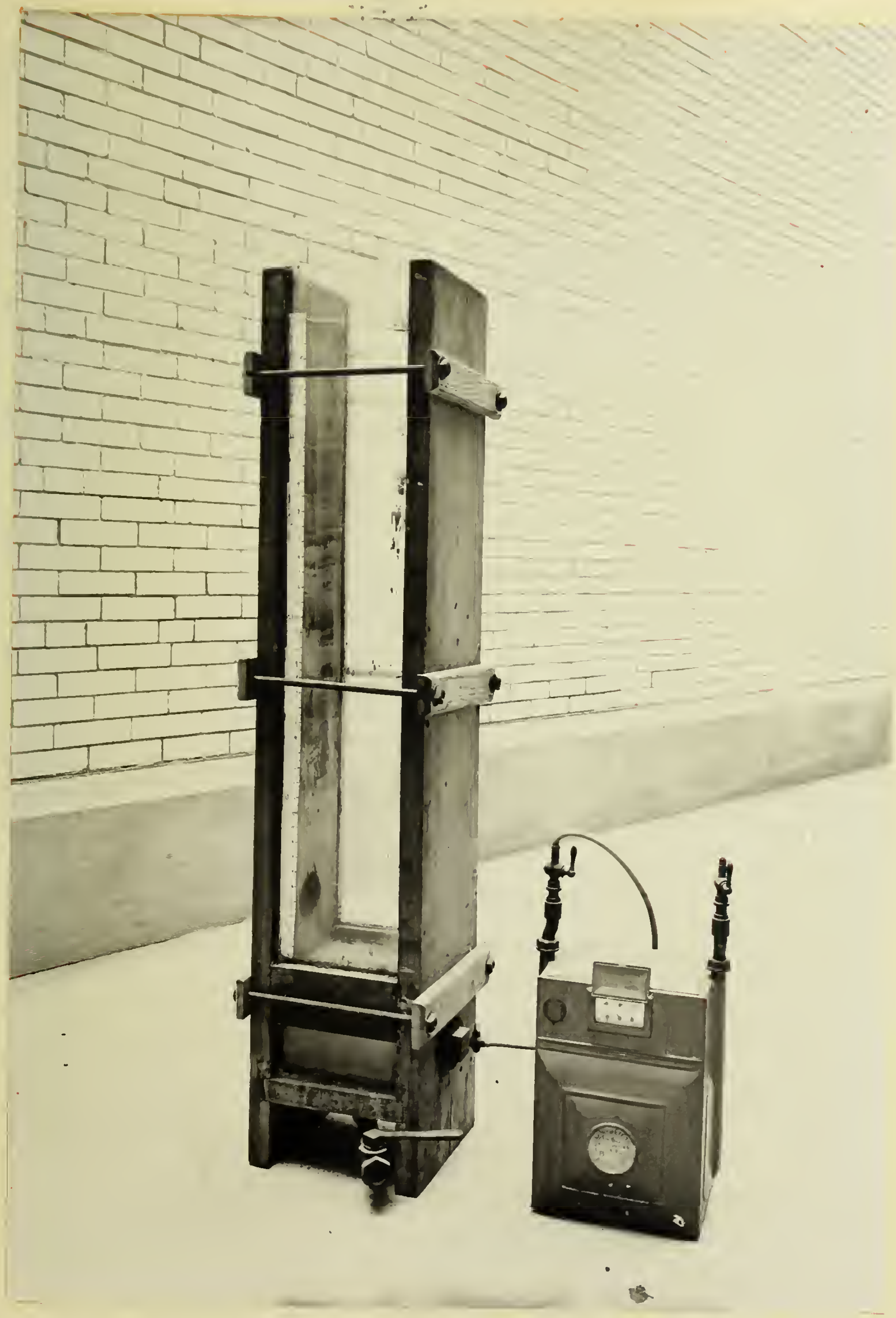
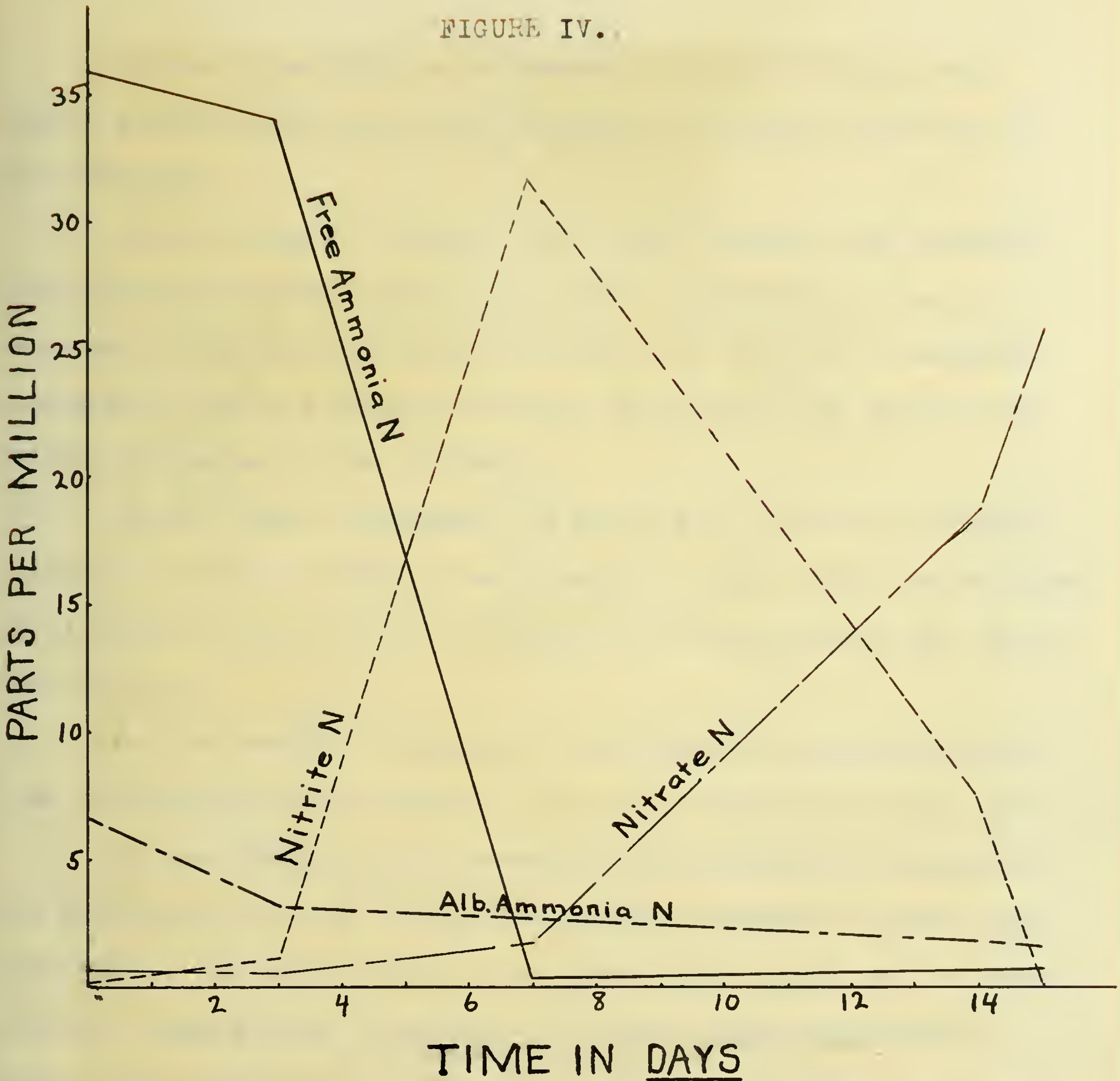


FIGURE IV.




Aeration of sewage.

No activated sludge present.

Uniform distribution of air through porous plate.

36 parts per million of ammonia nitrogen in the raw sewage produced 25.9 parts per million of nitrate nitrogen in the effluent.

In the second treatment, the time required for complete nitrification was but four days, with a reduction of the air required to 1,270 cubic feet; 34 parts per million of ammonia nitrogen in the raw sewage produced 23.8 parts per million of nitrate nitrogen in the effluent.

In the third treatment, 33 parts per million of ammonia nitrogen in the raw sewage was changed to 22.3 parts per million of nitrate nitrogen in the effluent in two days, with 720 cubic feet of air.

In the twelfth treatment, nitrification was complete in less than eight hours with the use of less than 128 cubic feet air.

In the thirty-first treatment with sludge and sewage in the proportion of 1:5, nitrification was complete in less than five hours; 35 cubic feet of air were used, equal to .20 cubic feet per square foot of surface area per minute or about 3 cubic feet per gallon of sewage. The effluent after one hour's aeration was perfectly stable, and did not decolorize methylene blue in twelve days.

27 parts per million of ammonia nitrogen in the raw sewage produced 22.1 parts per million of nitrate nitrogen in the effluent. (Table V, Fig. V).

The results shown in the short period of aeration were excellent, but it was learned from later operation that such

TABLE V.

AERATION OF SEWAGE

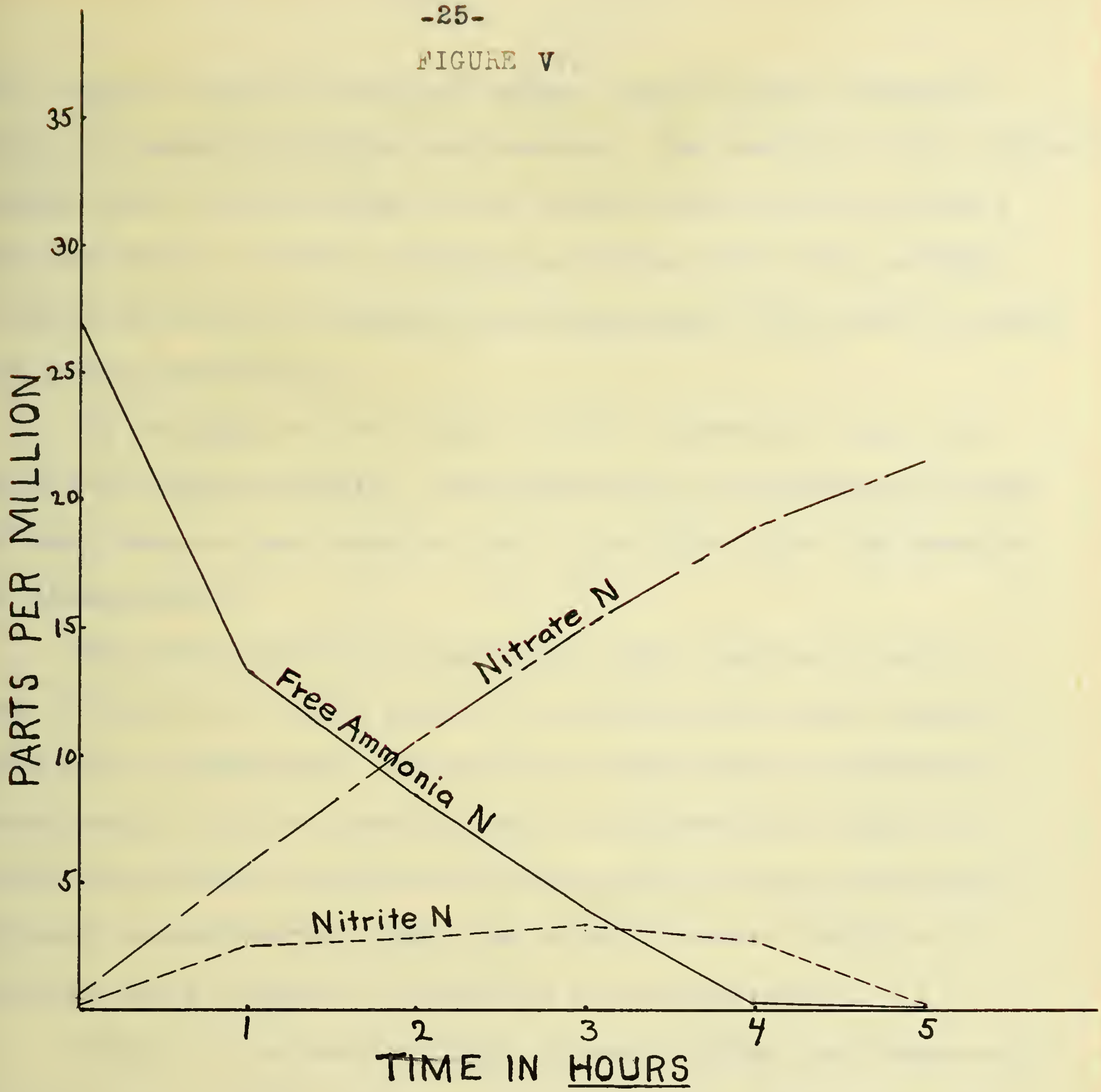
Activated Sludge Present.

1 sludge: 5 sewage.

Uniform distribution of Air through Porous Plate

| Date. | Time Hours. | Nitrogen Parts per million Ammonia | Nitrites | Nitrates |
|---|---|---|---|---|
| Feb. 24 | 0 | 27.00 | 0.05 | 0.59 |
| " " | 1 | 13.00 | 2.40 | 6.00 |
| " " | 2 | 8.20 | 2.80 | 10.80 |
| " " | 3 | 3.70 | 3.40 | 15.00 |
| " " | 4 | 0.20 | 2.60 | 10.60 |
| " " | 5 | 0.20 | 0.30 | 22.10 |

FIGURE V




Aeration of sewage.

Activated sludge present.

Uniform distribution of air through porous plate.

1 sludge : 5 sewage.

good results were not obtained unless aeration was continued until all ammonia nitrogen was removed. The quality of the effluent depends upon the condition of the sludge which in turn depends upon the extent to which previous aerations have been carried. By aerating until the ammonia has disappeared, the sludge becomes more highly activated.

In building up the sludge in the laboratory tank, the periods of aeration varied. The sewage was not changed at night and many sewages were aerated for a long time after the ammonia had disappeared.

With this method of operation, very excellent results were obtained in a short period of aeration, but such results could not be maintained, unless the sewage were over treated occasionally. If the ammonia N is not removed, there is slight formation of nitrites and nitrates, and each successive effluent becomes worse. When the sludge becomes inactive it requires quite a period of aeration to re-activate it.

Owing to the impossibility of controlling the temperature of the room at night, high temperatures occasionally prevailed at night, which may have caused the sludge to lose its activity.

When the sludge was in bad condition, it would not settle, appeared very colloidal, and sometimes had a slightly septic odor. Long aeration with occasional addition of fresh sewage would cause it to become normal.

Quantity of Sludge.

When the sludge had increased to about 33 per cent of the total volume it was removed to a depth of 6 inches above the plate

and dried. Eight portions of sludge were removed. Table VI gives the data for this work.

TABLE VI

QUANTITY OF SLUDGE OBTAINED FROM SEWAGE

Glass tank in Laboratory

| Date | Grams removed | Grams Solids Dry | Percent Water | Gallons Sewage added | Kg. dry sludge per million gallon sewage |
|---|---|---|---|---|---|
| Mar 15 | 4,400 | 75 | 98.3 | - - | - - |
| " 18 | 4,400 | 57 | 98.7 | - - | - - |
| " 23 | 9,400 | 132 | 98.6 | - - | - - |
| " 31 | 14,400 | 185 | 98.7 | 135 | 1,400 |
| Apr 8 | 9,750 | 121 | 98.8 | 196 | 620 |
| " 15 | 7,400 | 154 | 97.9 | 214 | 720 |
| " 30 | 8,300 | 185 | 97.8 | 360 | 515 |

Average percent water in sludge 98.4

There were wide variations in the amount of sludge formed per unit of sewage. When sludge was removed frequently, the amount formed seemed to be much greater than when it was allowed to remain in the tank for a longer period. For example, from March 23rd to March 26th, 3 days, 2550 kg. per million gallons, from March 26th to March 31st, 5 days, 1,400 kg. per million gallons, and from March 31st to April 8th, 8 days, only 620 kg. per million gallons were formed.

Sludge was probably liquefied by over treatment. This was verified by dividing a portion of sludge into two parts, drying one portion immediately, and aerating the other for 24 hours with 4 volumes of purified effluent before drying. 1.1 grams, or 5% was lost by the aeration.

| | |
|---|---|
| Weight of sample dried immediately | 23.7 grams |
| " " " " after 24 hours aeration | 22.6 " |
| Loss by over-aeration | 1.1 grams |

The high values obtained may be due to the fact that the sewage used was collected at 9 a.m. when the Champaign city sewage at the point of collection is strongest and contains the maximum amount of suspended matter, probably 2 to 3 times the average. If the suspended matter were completely removed from a sewage containing 300 parts per million of suspended matter, 1120 kg. of dry sludge would be obtained per 1,000,000 gallons of sewage. Sewage containing 135 to 365 parts per million of suspended matter, assuming 100% retention of suspended matter,

would give the amount of dried sludge obtained.

Analyses of the sludge were made by W. D. Hatfield*, as a

*Bartow & Hatfield, The Fertilizer Value of Activated Sludge. J. Ind. & Eng. Chem. Vol. 8, p. 17.

part of a thesis on the fertilizer value of activated sludge. The sludge was found to contain from 3.5 to 6.4% of nitrogen.

A phenomenon was noted in connection with the operation of the tank which was thought at the time to be of great importance. Small red worms were present in the sludge in such numbers that in places the sludge had a red appearance. The species was identified by Prof. Frank Smith, of the University of Illinois, as Aeolosoma hemprichi, an annelid worm about 2 to 5 mm. long and quite slender. It abounds in various kinds of fresh water bodies where there is an abundance of decaying organic matter, and thrives especially well where there is much fermentation, and in waters contaminated with sewage, provided there is an abundance of oxygen. It belongs to a group of worms in which reproduction occurs very rapidly by asexual methods. It feeds greedily and almost continuously on any small organic particles that it can obtain, and presumably destroys at least its own weight of organic matter every day.

Because of the facts noted above, it was thought that this worm was a very important agency in the purification of the sewage. However, it was proven by Robbins Russell* that the worms

* Met. and Chem. Eng. 13, 902 (1915)

were not essential, and that their presence was merely accidental and inconsequental. They were not found at any time in the larger scale experiments reported later, and have not been found at other places except at Washington, D. C., where they were found in laboratory experiments.

Their presence in the tank in the laboratory, and absence in the large tanks may be due to the fact that laboratory experiments were conducted in a light room, in a tank with glass sides, the temperature in the laboratory was higher, and the aeration was often carried past the point of complete ammonia removal, with subsequent formation of large amounts of nitrates. The worms disappeared at times of under-treatment, when effluents were putrescible, and it would seem as if nitrates were necessary for their growth and existence.

## Fish Life.

Considering that sustenance of fish life would be an excellent indication of the good quality of the effluent, some small fish obtained from the Salt Fork Creek near St. Joseph on April 17, 1915, were placed in a 20 liter jar which was filled with effluent from the tank. The liquid was aerated and changed each time the effluent was removed from the tank.

The fish seemed to thrive at first, but in three days two of the smallest died. In seven days another died, and in ten days all died shortly after the accidental addition of a putrescible effluent.

This test was inconclusive, as the quality of effluent was variable during the period of observation. When the added effluent was non-putrescible the fish seemed to suffer very little discomfort, and had all of the effluents been good, it is probable that the fish would have lived. It was proven, at least, that a non-putrescible effluent from the activated sludge process is not immediately toxic to fish.

## III. CONCRETE TANK EXPERIMENTS

The work with the laboratory tank was continued until April 30, 1915. On May 6th, 1915, experiments on a larger scale were inaugurated in four concrete tanks built in the basement of the University power plant. (Figs. V and VI.) This location was chosen because the main Champaign sewer passed this building, and it was the most convenient place that could be found for tapping the sewer. The conditions have been similar to those obtained by housing a plant.

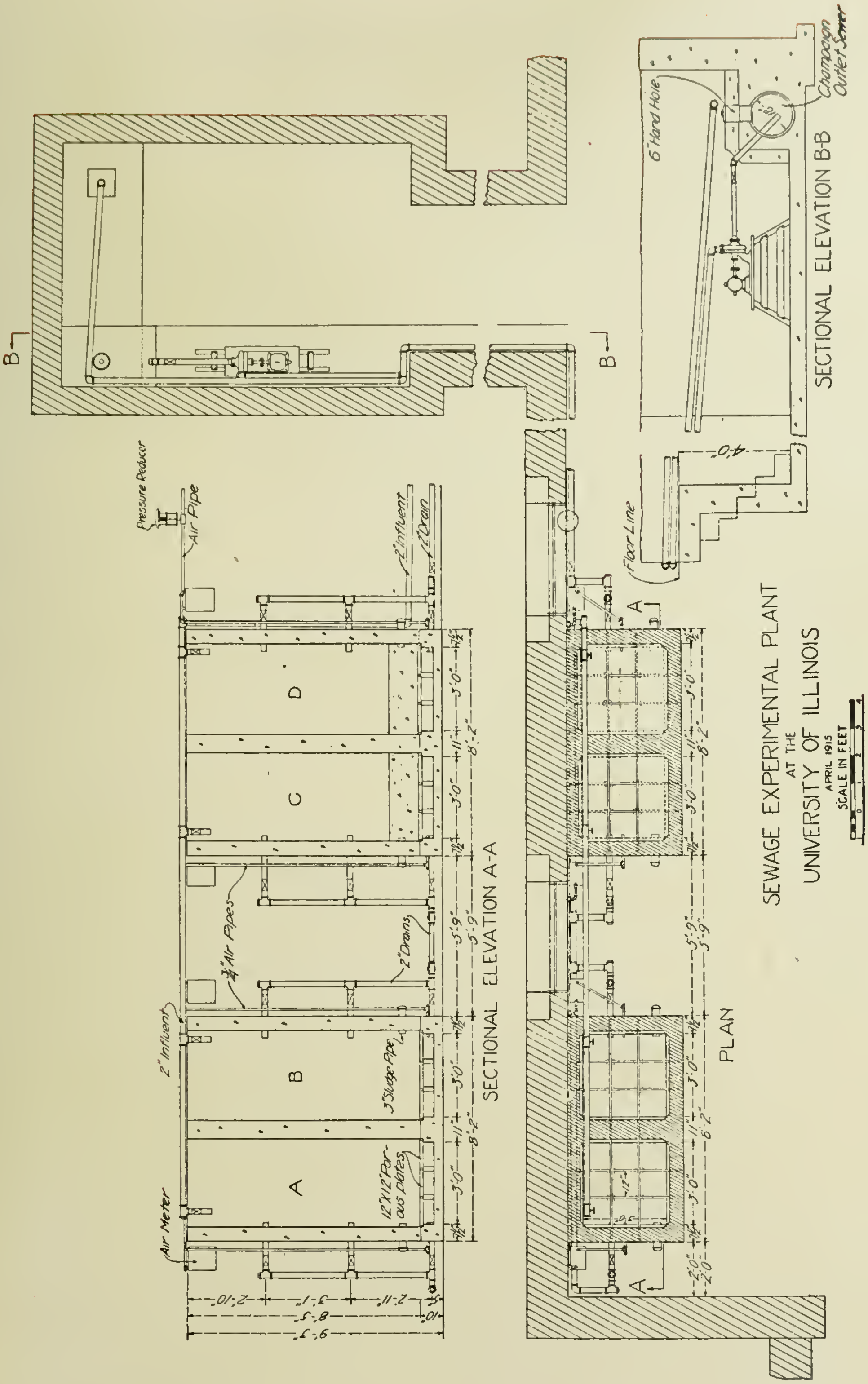
### Construction of Tanks.

Each tank is three feet two inches square, thus having an area of ten square feet. Each tank is eight feet five inches deep above one and one-half inch Filtros plates which are used for diffusing the air. These plates were adopted as the most satisfactory air-diffusing medium available.

In tanks A and B there are nine plates, each 12 inches square, covering the entire floor.

FIG.V

FIG.VI


SEWAGE EXPERIMENTAL PLANT
AT THE
UNIVERSITY OF ILLINOIS
APRIL 1915
SCALE IN FEET
SECTIONAL ELEVATION A-A
PLAN
SECTIONAL ELEVATION B-B
A
B
C
D
Air Meter
2" Influent
3/4" Air Pipes
2" Drains
3" Sludge Pipe
12"X12" Porous plates
Pressure Reducer
Air Pipe
2" Influent
2" Drain
6" Hand Hole
Champaign Outlet Sewer
Floor Line
4'-0"

In tank C there are three plates, covering three-tenths the area of the floor. They form a central trough, to which the concrete sides slope at an angle of 45°.

In tank D there is but one plate, covering one-tenth the area of the floor. The four concrete sides slope to the plate at an angle of 45°.

The plates are set on steel T-bars four inches above the bottom of the tank. The space below is drained by a 2 inch pipe, and when the tank is being drained air pressure is released by a pet-cock attached to a 1 inch pipe. If the pressure is not released when the water level is being lowered, bubbles of air pass through the plates and stir up the sludge and supernatant liquid.

The air, obtained from the University compressed air plant at a pressure of 80 pounds, is reduced by a pressure reducing valve to 8 pounds and is further regulated by a hand-operated valve before passing through meters on each tank. These meters are the ordinary gas meters. They were tested by the gas company during the course of the experiments, and were found to register with a fair degree of accuracy. The pressure under which the air enters the tank is but little more than that necessary to balance the hydrostatic pressure of the sewage. It is equivalent to 8 inches of mercury, or a little less than 4 pounds per square inch. The friction in passing through the plates adds but a fraction of a pound pressure.

Two outlets for the effluent are, respectively, 2 feet, 6 inches; and 5 feet, 7 inches above the plates. For the later

experiments changes were made in the outlets.

Raw sewage was pumped as needed by a 2 inch centrifugal pump direct connected to a 2 h.p., 3 phase motor. This pump will fill one tank in 6 minutes. Each tank can be drained to the lower outlet in 8 minutes.

A 3 inch sludge pipe with a quick-opening valve was introduced into each tank 5 inches above the plates, for removing sludge when necessary. This design was faulty as the pipe should have been just above the plates.

Plan of Operation.

The operation of the four tanks was so planned that special features might be studied. Great flexibility of operation was possible, the variables being, 1. Strength of sewage; 2, Amount of Air; 3, Quantity of Sludge; 4, Temperature; 5, Length of Aeration; 6, Air diffusing area. The most constant factor was the quantity of sewage treated per filling, and this varied slightly according to the amount of sludge present. Approximately 400 gallons were added at each filling.

Building up Sludge.

The rate of building up activated sludge is of great importance from a practical standpoint. In the original work of Ardern and Lockett* and in our first work (See page 10)

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*J. Soc. Chem. Ind., 33, 523-39.

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fresh sewage after each addition was aerated until all ammonia nitrogen was removed. This method of procedure requires nearly

two months for the building up of sufficient activated sludge to operate a plant. In the meantime a very small portion of the sewage would be treated. In order to shorten this long period of preparation, sludge was built up by removing the effluent before the ammonia nitrogen was entirely oxidized to nitrate nitrogen. In this way, from the start, sewage was partially purified, and sludge was accumulated more rapidly. The rapid method of building up sludge was developed by comparative operation of two tanks. Tanks A and B were put in operation on May 5, 1915. The sewage in tank A was aerated eleven days until all free ammonia was gone, (see Table VII), that in B was changed every 24 hours during the same period (see Table VIII).

TABLE VII

BUILDING UP SLUDGE

Aeration of sewage in tank A.

| Date | Hours Aerated | Cu. Ft. Air | Analysis: Free Ammonia | Nitrite Nitrogen | Nitrate Nitrogen | Oxygen Consumed | Total Organic Nitrogen | Stability |
|---|---|---|---|---|---|---|---|---|
| May 5 | 0 | 0 | 28.0 | -.- | -.- | 88.0 | 21.6 | - - |
| " 6 | 18.5 | 3,600 | 16.0 | .35 | .95 | 21.2 | 10.4 | - - |
| " 7 | 42.5 | - - - | 15.0 | .35 | - - | 22.0 | 5.3 | - - |
| " 8 | 72. | 9,430 | 12.0 | .45 | .75 | 22.8 | 5.0 | - - |
| " 9 | 98. | 12,480 | 18.0 | .45 | .85 | 20.8 | 4.2 | - - |
| " 10 | 121. | 15,400 | 17.0 | .50 | 1.00 | 20.4 | 4.0 | 90 |
| " 11 | 144. | 18,220 | 14.0 | 1.5 | .10 | 20.4 | 3.6 | 96 |
| " 12 | 167. | 21,440 | 14.0 | 2.0 | .10 | 22.8 | 4.2 | 100 |
| " 13 | 192. | 25,340 | 15.0 | 3.3 | .10 | 24.0 | 5.2 | 100 |
| " 14 | 218. | 29,100 | 13.0 | 4.7 | .20 | 25.2 | 4.8 | 100 |
| " 15 | 238. | 32,080 | 10.0 | 12.5 | .50 | 32.8 | 5.6 | 100 |
| " 16 | 270. | 35,930 | 0.4 | 26.0 | 1.0 | 35.0 | 6.2 | 100 |

TABLE VIII

BUILDING UP SLUDGE

Aeration of sewage in tank B.

| Date | Raw or Effluent | Cu.Ft. Air | Hours Aerated | Analysis: Ammonia | Nitrite | Nitrate | Oxygen Consumed | Total Organic Nitrogen | Stability |
|---|---|---|---|---|---|---|---|---|---|
| May 5 | Raw | 2830 | 24 | 28.0 | - - | - - | 88.0 | 21.6 | - - |
| " 5 | Eff. | - - | - | 16.0 | .35 | .95 | 21.6 | 10.4 | - - |
| " 6 | Raw | 2430 | 23 | 19.0 | - - | - - | 60.0 | 19.3 | - - |
| " 6 | Eff. | - - | - | 15.0 | .45 | .95 | 22.8 | 9.9 | 37 |
| " 7 | Raw | 3840 | 23 | 24.0 | - - | - - | 42.0 | 12.0 | - - |
| " 7 | Eff. | - - | - | 15.0 | .50 | 1.4 | 22.4 | 6.2 | 75 |
| " 8 | Raw | 2660 | 25 | 16.0 | - - | - - | 29.0 | 9.6 | - - |
| " 8 | Eff. | - - | - | 11.0 | .4 | 1.8 | 12.0 | 5.4 | 84 |
| " 9 | Raw | 2200 | 22 | 21.0 | - - | - - | 47.0 | 15.2 | - - |
| " 9 | Eff. | - - | - | 16.0 | .5 | 2.3 | 14.4 | 5.3 | 84 |
| " 10 | Raw | 1650 | 21 | 20.0 | - - | - - | 46.0 | 11.5 | - - |
| " 10 | Eff. | - - | - | 12.0 | 1.0 | 1.0 | 15.2 | 4.2 | 90 |
| " 11 | Raw | 3990 | 22 | 18.0 | - - | - - | 75.0 | 15.0 | - - |
| " 11 | Eff. | - - | - | 8.0 | 1.7 | 1.0 | 21.2 | 5.0 | 90 |
| " 12 | Raw | 1750 | 24 | 19.0 | - - | - - | 83.0 | 16.7 | - - |
| " 12 | Eff. | - - | - | 10.0 | 1.6 | .5 | 19.2 | 4.6 | 96 |
| " 13 | Raw | 2450 | 24 | 18.0 | - - | - - | 52.0 | 12.2 | - - |
| " 13 | Eff. | - - | - | 11.0 | 3.6 | .4 | 23.6 | 5.4 | 97 |
| " 14 | Raw | 1530 | 19 | 27.0 | - - | - - | 64.0 | 15.4 | - - |
| " 14 | Eff. | - - | - | 18.0 | 5.0 | .5 | 25.2 | 5.0 | 100 |
| " 15 | Raw | 3900 | 31 | 23.0 | - - | - - | 70.0 | 12.5 | - - |
| " 15 | Eff. | - - | - | 5.0 | 15.0 | 1.0 | 50.0 | 6.5 | 100 |
| " 16 | Raw | 1420 | 16 | 26.0 | - - | - - | 171.0 | 32.6 | - - |
| " 16 | Eff. | - - | - | 4.0 | 20.0 | 2.0 | 48.0 | 5.4 | 100 |

In the same time 12 times as much sewage has been treated in B as in A. After one hour's settling in Imhoff cones, there was shown to be 1 per cent of sludge in A, and 10 per cent in B. The effluent from tank B on May 16th, after 11 days, was clearer than that from tank A.

In eleven days' continuous aeration of the sewage in tank A, using 35,930 cubic feet of air,ammonia nitrogen had been reduced from 28 to 0.4 parts per million, the nitrite nitrogen increased to 26 parts per million, the nitrate to 1 part per million. Oxygen consumed was reduced from 88. to 35. parts per million, total organic nitrogen from 21.6 to 6.2 parts per million, and the supernatant liquid had a stability of 100 per cent.

By one day's aeration, the eleventh day, of the sewage in tank B using 1,420 cubic feet of air , ammonia nitrogen was reduced from 26.0 to 4.0 parts per million. Nitrite nitrogen increased to 20 parts per million, the nitrate nitrogen to 2.0 parts per million. Oxygen consumed was reduced from 171. to 48. parts per million, and total organic nitrogen from 32.6 to 5.4 parts per million, and the effluent was 100 per cent stable.

The results obtained by changing the sewage in tank B every day were so much better than were obtained by the continuous aeration of tank A that this experiment in Tank A was discontinued.

Tank B was continued in operation, changing the sewage every 24 hours, until, after 15 days, ammonia nitrogen in the effluent

was below 1.0 part per million. Then the sewage was changed every 12 hours; after 8 days more, ammonia nitrogen in the effluent was again below 1.0 part per million. Then the sewage was changed every 6 hours. After four more days ammonia nitrogen in the effluent was below 1.0 part per million. The sewage was well nitrified by this sludge, and it had the appearance and properties of sludge built up by complete nitrification of each quantity of sewage added.

This comparison indicated that it was not necessary to aerate until all the ammonia nitrogen was removed, in order to build up a satisfactory sludge.

Activated sludge was accumulated in tank A by changing the sewage every 12 hours. The data correspond to that for tank B on the 24 hour schedule. Stable effluents were obtained in 7 days; complete removal of ammonia nitrogen occurred in 18 days, after which the sewage was changed every 6 hours. The effluents obtained from tank A during this 6 hour cycle were in general as good as those obtained from tank B, in which sludge had been built up by changing once a day.

In a later experiment in tank C, sludge was built up by changing the sewage once in 6 hours. Stable effluents were obtained in 15 days; removal of ammonia nitrogen below one part per million occurred in 20 days. The sludge built up in this way had the same characteristics as sludge accumulated by changing the sewage only when all the ammonia nitrogen was removed, and was seemingly just as highly "activated".

[illegible]

[illegible]

[illegible]

[illegible]

Activated sludge can therefore be built up by changing the sewage as often as once in six hours.

It has been thought that the accumulation of sludge would be a long, tedious process, and to cut down the time, slurry from sprinkling filters*, Imhoff sludge**and other kinds of sludge

*Ardern & Lockett, J. Soc. Chem. Ind. XXXIII, 1124.
**Canadian Engineer, 30, 476.

have been proposed as "starters" for the process. Sufficient sludge can be obtained from the raw sewage in a week, by changing it every six hours. None of these starters need by used. A considerable degree of purification can be obtained from the beginning of operation. If by any chance the operation of a plant is stopped, it can again be put in service in a short time.

Operation of Tanks A and B.

Tanks A and B were operated continuously from May 21 until November first. During this time 400 gallons of sewage was applied per filling. Effluents were removed and sewage added four times a day, except when the influent pipe was plugged up by rags or the motor refused to work. Such accidents account for most of the periods of over-aeration. The amount of air applied and the time of aeration was variable. The amount of sludge remained approximately constant after 25 % had been built up. Only once was sludge removed from each tank. On June 30th, the sludge in tank A was well stirred, and 6 inches were removed and dried on a sand bed; the sludge was further dried on a steam bath, to a final weight of 485 grams. On July 9th, 6 inches were removed from tank B; the dried sludge weighed 1660 grams.

[illegible]

It was quite surprising to find that even though sludge was not removed, only 30% was accumulated in tanks A and B. The failure to accumulate sludge may have been because it was drawn off with the effluent, or it may have been digested and liquefied in the tank as fast as it was formed. Sludge is decreased by over-aeration, (see p.23) and at times during this experiment with tanks A and B the sludge was over-aerated--that is, was aerated beyond the disappearance of ammonia nitrogen. Warm weather may have accelerated the digestion. Owing to the failure to accumulate sludge no data concerning the amount of sludge formed were obtained. Special determinations were made later with tank C.

Analyses of the raw sewage and effluents from tank A from May 21 to November 1, were averaged by weeks. (see table IX). Similar data were obtained for tank B but they are omitted since they are practically indentical with those for tank A.

During the first period, from May 21 to 24 with very little sludge, effluents were not stable even with 12 hours aeration and 2.0 cubic feet of air per gallon.

From May 25 to 31, effluents were very good with 11 hours aeration and 1.5 cubic feet of air per gallon. From June 1 to 7th, effluents were good. Aeration, 11 hours, 1.5 cubic feet per gallon.

During the period of June 8th to 14th, the time of aeration was cut down to 5 hours, and the air to less than 1 cubic foot per gallon. The effluents from the weak 3 a. m. sewage were stable, but those from the 9 a. m., 3 p.m. and 9 p.m. sewages were

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

not good. We have considered that a stability under 70 indicates a poor effluent.

From June 15 to 21, with about .8 cubic foot of air per gallon, all effluents from 3 a.m. sewages were stable; those from 9 a.m. sewages were good, but the effluents from the 3 p.m. and 9 p.m. sewages were quite poor.

From June 22 to 28, the results confirmed those for the previous week.

During the period June 29th to July 5th, with 1 cubic foot of air, all effluents from the 3 a.m. sewages were stable, but even with 1.5 cubic foot the other effluents were very bad.

From July 6th to 12th, more air was applied, average 2.5 cubic feet, and longer aeration given, resulting in good effluents from all sewages.

During the next week, July 13th to 19th, the air was again reduced to about 1.0 cubic foot per gallon, the time to 5 hours; effluents were not good.

From July 20th to 26th, with 1.0 cubic foot per gallon and 4.5 hours aeration, all effluents except those from 3 a.m. sewage were bad.

From July 27th to August 2nd, with .9 cubic foot per gallon, and 4.5 hours aeration, all effluents were good, but due to rains the raw sewage was very weak.

During the entire month of August nitrification was good, and all effluents were excellent. During the first and last weeks, however, due to the excessive rainfall, the raw sewage was very weak.

[illegible]

Normal sewage was obtained from August 10th to 23rd, and during this period very good effluents were obtained by using 1.3 cubic feet per gallon and 4.6 hours aeration.

During the first week of September, with 6 hours aeration and 1.3 cubic feet of air per gallon, good effluents were obtained from normal sewage.

From September 7th to 13th, with 5 hours aeration and 1.1 cubic feet of air per gallon, all effluents except that from the 3 a.m. sewage were very bad.

During the period September 14th to 20th, with 5 hours aeration and 1.0 cubic foot of air, effluents were fair. The raw sewage was weak during this week.

From September 21st to October 4th, even with 1.9 cubic feet of air per gallon and 6.7 hours aeration, all effluents were very bad.

In order to determine whether the quality of the effluents could be improved by aerating the sludge alone for a certain period, no sewage was added at 3 a.m. and the sludge alone was aerated from 3:30 to 9:00 a.m. This procedure was followed from October 5 to 18, but all effluents were very bad.

From October 19 to November 1 sewage was added four times a day, but the schedule of operation was changed somewhat. The weak 5:30 a.m. sewage was easily nitrified, the 9:30 a.m. gave a fairly good effluent with an excessive amount of air and a long period of aeration, while the 4:30 p.m. and 11 p.m. sewages gave bad effluents with normal amounts of air and a normal period of aeration.

## TABLE IX.

## RECORD OF OPERATION, TANK A

| Week | Time of filling | Hours aerated | Air Cu.Ft. | RAW Ammonia N | ANALYSIS EFFLUENT Ammonia N | Nitrite N | Nitrate N | Stability |
|---|---|---|---|---|---|---|---|---|
| May 21-24 | 9-11A.M. | 12.7 | 800 | 37.8 | 26.5 | .15 | .5 | 24 |
| " 25-31 | " | 10.7 | 740 | 21.4 | 12.4 | 3.6 | 3.3 | 83 |
| " " | 10-11P.M. | 11.6 | 590 | 17.4 | 9.6 | 4.9 | 3.5 | 91 |
| June 1-7 | 10-11A.M. | 11.0 | 600 | 22.7 | 5.6 | 2.8 | 4.5 | 91 |
| " " | 11P.M. | 11.0 | 510 | 18.7 | 6.2 | 2.1 | 5.8 | 80 |
| " 8-14 | 3A.M. | 5.0 | 320 | 10.2 | 3.8 | 1.7 | 6.9 | 99 |
| " " | 9 " | 5.8 | 390 | 31.7 | 14.3 | 1.3 | 2.1 | 70 |
| " " | 3P.M. | 5.0 | 310 | 17.8 | 14.3 | .1 | .6 | 54 |
| " " | 9 " | 5.0 | 300 | 21.7 | 12.4 | .6 | .9 | 74 |
| " 15-21 | 3A.M. | 5.0 | 270 | 11.8 | 6.6 | 1.9 | 4.2 | 100 |
| " " | 9 " | 5.0 | 320 | 28.3 | 16.7 | .7 | 1.3 | 81 |
| " " | 3P.M. | 5.0 | 290 | 17.1 | 14.3 | .5 | .4 | 48 |
| " " | 9 " | 5.0 | 270 | 19.3 | 14.0 | .6 | .5 | 52 |
| " 22-28 | 3A.M. | 5.1 | 310 | 12.9 | 7.0 | 3.1 | 3.2 | 100 |
| " " | 9 " | 5.1 | 390 | 29.7 | 17.7 | .9 | .8 | 67 |
| " " | 3P.M. | 4.7 | 300 | 17.3 | 13.2 | .2 | .3 | 53 |
| " " | 9 " | 5.0 | 330 | 20.7 | 12.5 | .9 | .4 | 70 |
| "29-July 5 | 3A.M. | 5.0 | 400 | 16.7 | 10.8 | .5 | 1.8 | 100 |
| " " | 9 " | 4.9 | 520 | 32.3 | 22.2 | .1 | .0 | 17 |
| " " | 3P.M. | 6.6 | 930 | 24.5 | 16.2 | .6 | .2 | 68 |
| " " | 9 " | 5.0 | 380 | 22.0 | 16.3 | .0 | .4 | 45 |
| July 6-12 | 3A.M. | 4.5 | 1170 | 4.7 | .3 | 1.1 | 11.1 | 100 |
| " " | 9 " | 14.5 | 1700 | 24.3 | 12.3 | 4.7 | 4.6 | 78 |
| " " | 3P.M. | 4.0 | 530 | 15.1 | 6.9 | 3.6 | 3.8 | 74 |
| " " | 9 " | 6.1 | 540 | 12.6 | 6.2 | 3.3 | 4.0 | 82 |
| " 13-19 | 3A.M. | 4.5 | 370 | 8.2 | 2.0 | 1.8 | 2.6 | 99 |
| " " | 9 " | 4.5 | 530 | 23.7 | 10.3 | 1.3 | 2.0 | 61 |
| " " | 3P.M. | 4.5 | 420 | 13.3 | 8.1 | .1 | .5 | 62 |
| " " | 9 " | 6.2 | 400 | 17.3 | 9.9 | .7 | 1.0 | 77 |
| " 20-26 | 3A.M. | 4.5 | 420 | 10.5 | 5.2 | 1.6 | 4.7 | 98 |
| " " | 9 " | 4.5 | 510 | 31.1 | 17.8 | .8 | 1.1 | 68 |
| " " | 3P.M. | 4.5 | 440 | 17.4 | 13.9 | .3 | .6 | 56 |
| " " | 9P.M. | 4.5 | 350 | 18.8 | 11.3 | .4 | 1.0 | -- |

TABLE IX (Continued)

| Week | Time of filling | Hours aerated | Air Cu.Ft. | RAW Ammonia N | EFFLUENT Ammonia N | EFFLUENT Nitrite N | EFFLUENT Nitrate N | EFFLUENT Stability |
|---|---|---|---|---|---|---|---|---|
| Jul.27-Aug.2 | 3A.M. | 5.4 | 420 | 5.0 | 2.1 | 2.5 | 9.5 | 100 |
| " " " " | 9 " | 4.5 | 350 | 14,7 | 9.3 | 1.3 | 10.8 | 85 |
| " " " " | 3P.M. | 4.5 | 350 | 7.9 | 6.1 | .7 | 6.7 | 80 |
| " " " " | 9 " | 4.5 | 350 | 8.7 | 4.3 | 1.5 | 8.7 | 75 |
| Aug.3-9 | 3A.M. | 4.5 | 320 | 4.3 | .2 | | 16.2 | 100 |
| " " | 9 " | 5.4 | 410 | 17.4 | 7.2 | | 12.3 | 93 |
| " " | 3P.M. | 4.5 | 340 | 9.2 | 6.1 | | 7.7 | 90 |
| " " | 9 " | 4.5 | 360 | 10.4 | 2.4 | | 9.6 | 100 |
| Aug.10-16 | 3A.M. | 4.5 | 350 | 5.9 | .7 | | 8.6 | 95 |
| " " | 9 " | 5.4 | 610 | 30.1 | 8.2 | | 6.2 | -- |
| " " | 3P.M. | 4.5 | 580 | 16.3 | 1.5 | | 5.7 | -- |
| " " | 9 " | 4.5 | 420 | 16.1 | 2.9 | | 4.1 | -- |
| Aug.17-23 | 3A.M. | 4.5 | 490 | 6.8 | .0 | | 9.7 | -- |
| " " | 9 " | 4.5 | 520 | 28.8 | 10.7 | | 5.1 | -- |
| " " | 3P.M. | 4.5 | 570 | 12.8 | 4.4 | | 5.8 | -- |
| " " | 9 " | 4.5 | 420 | 14.7 | 6.3 | | 3.6 | -- |
| " 24-30 | 3A.M. | 4.5 | 380 | 3.4 | .0 | | 14.5 | 100 |
| " " | 9A.M. | 4.5 | 520 | 17.7 | 1.1 | | 16.2 | 100 |
| " " | 3P.M. | 4.5 | 530 | 11.3 | .7 | | 10.4 | 100 |
| " " | 9P.M. | 4.5 | 400 | 10.8 | .0 | | 12.0 | 100 |
| Aug.31-Sep.6 | 3A.M. | 4.5 | 410 | 5.7 | 1.0 | | 7.9 | 100 |
| " " " " | 9 " | 7.1 | 580 | 25.1 | 5.8 | | 7.5 | 95 |
| " " " " | 3P.M. | 7.5 | 640 | 10.8 | 5.2 | | 2.1 | 75 |
| " " " " | 9 " | 5.5 | 490 | 14.7 | 4.5 | | 5.1 | 92 |
| Sept.7-13 | 3A.M. | 4.5 | 330 | 8.7 | 3.6 | | 2.6 | 96 |
| " " | 9A" | 6.2 | 630 | 32.4 | 10.4 | | 2.7 | 60 |
| " " | 3P.M. | 4.5 | 350 | 15.8 | 13.6 | | .0 | 28 |
| " " | 9 " | 4.5 | 320 | 17.1 | 12.6 | | .3 | 44 |
| Sept.14-20 | 3A.M. | 6.2 | 410 | 3.9 | 2.6 | | 2.6 | 90 |
| " " | 9A.M. | 4.5 | 430 | 21.8 | 12.9 | | .0 | 73 |
| " " | 3P.M. | 4.5 | 430 | 13.1 | 8.9 | | .1 | 80 |
| " " | 9P.M. | 4.5 | 380 | 14.9 | 9.8 | | .8 | 63 |
| Sept.21-27 | 3A.M. | 4.5 | 250 | 8.3 | 8.1 | | .3 | 60 |
| " " | 9 " | 8.8 | 1450 | 30.6 | 18.3 | | 2.3 | 55 |
| " " | 3P.M. | 4.5 | 500 | 18.8 | 15.5 | | .3 | 22 |
| " " | 9 " | 4.5 | 360 | 20.9 | 15.9 | | .0 | 28 |

TABLE IX (Concluded)

| Week | Time of filling | Hours aerated | Air Cu.Ft. | RAW Ammonia N | EFFLUENT Ammonia N | EFFLUENT Nitrite N Nitrate N | EFFLUENT Stability |
|---|---|---|---|---|---|---|---|
| Sept.28-Oct.4 | 3A.M. | 17.5 | 1480 | 13.4 | 6.9 | 5.1 | 84 |
| " " | 9 " | 6.5 | 690 | 32.5 | 18.5 | 1.1 | 75 |
| " " | 3P.M. | 4.5 | 780 | 18.3 | 10.3 | .0 | 30 |
| " " | 9P.M. | 4.7 | 580 | 22.1 | 12.2 | 1.3 | 51 |
| Sludge alone aerated from 3;30-8:00 A.M. | | | | | | | |
| Oct.5-11 | 3A.M. | 9.6 | 1300 | ---- | ---- | --- | -- |
| " " | 9 " | 5.8 | 610 | 39.6 | 27.7 | .1 | 23 |
| " " | 3P.M. | 4.3 | 600 | 21.1 | 16.2 | .0 | 20 |
| " " | 9 " | 4.5 | 470 | 26.1 | 18.3 | .0 | 16 |
| " 12-18 | 3A.M. | 12.6 | 1800 | ---- | ---- | --- | -- |
| " " | 9 " | 4.6 | 650 | 41.6 | 28.0 | 1.0 | 38 |
| " " | 3P.M. | 4.9 | 630 | 21.5 | 19.4 | .2 | 33 |
| " " | 9 " | 4.5 | 570 | 28.2 | 18.8 | 1,2 | 56 |
| All sewages aerated. | | | | | | | |
| " 19-25 | 6A.M. | 5.3 | 1110 | 8.8 | 6.9 | 5.1 | 100 |
| " " | 10 " | 5.4 | 850 | 40.0 | 25.4 | 1.5 | 76 |
| " " | 5P.M | 5.7 | 670 | 21.6 | 18.1 | .0 | 41 |
| " " | 12 " | 4.6 | 660 | 30.5 | 21.7 | 1.3 | 65 |
| Oct.26-Nov.1 | 6A.M. | 4.4 | 1020 | 9.0 | 7.8 | 2.9 | 98 |
| " " | 10 " | 6.7 | 1530 | 38.2 | 20.8 | 2.1 | 78 |
| " " | 5P.M. | 4.7 | 900 | 19.2 | 13.4 | .1 | 57 |
| " " | 12 " | 5.1 | 660 | 26.3 | 17.9 | .2 | 55 |

Conclusions.

1. The fill and draw system gives quite variable results, dependent upon the strength of the sewage, the condition of the sludge, and the amount of air applied, or possibly upon the design of the tank.

2. Weak sewage can be well nitrified in contact with 25% sludge by 4 hours aeration and 1.0 cubic foot of air per gallon; average sewage requires 4 to 5 hours aeration, and 1.3 cubic feet of air per gallon; strong sewage requires more than 5 hours aeration and more than 1.5 cubic feet of air per gallon.

3. The design of tanks A and B is poor. The distribution of air with the bottom entirely covered with plates is not uniform through all the plates. Pockets of sludge or grit may have accumulated in places where the air was not passing through the plates. Since the sewage was not passed through a grit chamber much of the sewage contained grit and mud which tended to deposit upon and clog up some of the plates, and to furnish a place for an accumulation of sludge. Such "sludge-banks" may have become anaerobic, and if stirred, would cause a marked deterioration in the quality of the sludge.

Amount of Plate Surface Necessary.

A comparative test was run with tanks C and D, in order to determine the relative efficiency of the diffusion area in these tanks.

The bottom of tank C contains 3 square feet of Filtros plates per 10 square feet of floor area; the bottom of

tank D contains 1 square foot. The tanks were operated from July 6 to 19, (see table X) under as nearly as possible the same conditions of sewage and air. The sewage was changed 47 times, an average of four times a day.

The effluents from tank D were uniformly poorer than those from tank C. It is possible that the difference was due to the fact that but .9 cubic foot of air per gallon was used with tank D, and 1.13 cubic feet per gallon was used with tank C. It is more probable that the poor results were due to a too small distribution area in tank D. The amount of air given tank D was always sufficient to keep the sludge well mixed with the sewage, but not much more air could have been forced into tank D without excessive agitation of the sewage and sludge. Tank C has given uniformly the best results. D has failed to give good results at any time.

TABLE X.

Amount of plate surface needed.

Tank C, 3/10 total floor area.

Tank D, 1/10 total floor area.

| Number of fillings | Hours Aerated | Cu. Ft. Air per 400 gals sewage | Analysis: Raw Ammonia | Analysis: Effluent Ammonia | Analysis: Effluent Nitrite | Analysis: Effluent Nitrate | Analysis: Effluent Stability |
|---|---|---|---|---|---|---|---|
| Tank C | | | | | | | |
| 47 | 4.9 | 454 | 14.6 | 10.8 | .5 | 1.4 | 50 |
| Tank D | | | | | | | |
| 47 | 4.9 | 360 | 14.6 | 12.1 | .1 | .5 | 18 |

Conclusion

A diffusion area covering 3/10 the floor surface gives much better results than a diffusion area covering all, or 1/10, the floor surface. The ratio might possibly be reduced to 1/6 or 1/7 the area without marked deterioration in the quality of the effluents, but we were unable to test other diffusion areas.

The Filtros plates are a good medium for air diffusion. They break up the air into fine bubbles, and have given no trouble through clogging, breaking, etc. In large installations plates of uniform porosity must be used. The manufacturers are attempting to produce a more uniform grade of plates for use in sewage aeration. The plates must be set as nearly as possible at the same level, as a variation of 1/4 inch will cause uneven air distribution.

Quantity of Sludge Formed.

The failure to accumulate sludge in tanks A and B has been noted. In order to avoid loss of sludge during the removal of the effluent several short lenghts of 2 inch pipe, loosely threaded together so that they would collapse, were connected to the lower outlets of tanks A, B and C. During aeration the free end was held above the surface of the sewage by means of a chain. After the sludge has settled, the open end of the effluent pipe could be lowered to within a few inches of the sludge, without drawing off sludge with the effluent.

In order more surely to prevent loss of sludge a

hollow cast-iron frame one foot square and 6 inches wide was screwed onto the free end of the collapsible effluent pipe in tank C. The sides of this frame were covered with a 16 mesh copper screen, through which the effluent had to flow. A few determinations of the amount of sludge formed have been made in tank C.

A determination of the actual weight of sludge formed in 12 days has been made. Prior to July 20, 1915 tank C had been filled 47 times, each time with an average of 435 gallons. A total of 20,400 gallons of sewage was added.

The sludge was placed on a small sludge-drying bed, 4 by 8 feet in area. The sides of the bed were of 12 by 2 inch boards. Coarse sand was placed in this frame to a depth of 8 inches and cheese-cloth was spread over the sand in order to avoid mixing sand with the sludge. Due to the rains this dried very slowly so that it was finally dried on a steam bath, 10,610 grams being produced.

If 20,400 gallons give 10.6 kg., <u>1,000,000 gallons will give 520 kg., or 1,150 lbs.</u>

Compared with later results, obtained indirectly, this value is high, perhaps due to contamination of the sludge by sand and gravel from the sludge drying bed.

It is difficult to use open sludge drying beds.

On November 5, sludge was removed from tank C. Part of it was placed on the sludge bed, and the remainder on another bed made of crushed coal, covered with cheese cloth. This sludge

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[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

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never did dry, because of rain, snow and cold weather, and the weight of the dry sludge was not obtained.

Tank C was operated from January 6 to 25, 1916, changing the sewage usually four times a day. On January 25, after the effluent had been removed, the amount of sludge remaining was calculated. The solids in a aliquot portion of this sludge were determined and the amount of dry sludge calculated.

Fifty-four additions of sewage of 400 gallons each and three additions of 200 gallons each had been made. The data and calculations are given below.

Weight Dry Sludge.

| | |
|---|---|
| Depth of sludge in tank C | 30 inches |
| Quantity of sludge in tank C | 22 cu. ft. |
| Weight of sludge in tank C | 1386 lbs. |
| % solids in sludge | 1.17 % |
| Weight dry sludge | 16.2 lbs. |

Sewage Added.

(54 x 400) + (3 x 200) = 22,200 gallons

22,200 gallons give 16.2 lbs.

1,000,000 gallons give 750 lbs.

Tank C was operated in a similar manner from March 9 to 23, 1916. The same calculations were made as in the previous case.

Weight Dry Sludge.

| | |
|---|---|
| Depth of sludge in tank C | 30 inches |
| Quantity of sludge in tank C | 22 cu. ft. |
| Weight of sludge in tank C | 1386 lbs. |

| | |
|---|---|
| % solids in sludge | .98 % |
| Weight dry sludge | 13.6 lbs. |

Sewage Added.

(46 x 400) = 18,400 gallons.

18,400 gallons give 13.6 lbs.

1,000,000 gallons give 740 lbs.

The limited data available indicates that Champaign sewage produces from 740 to 1150 pounds of dry sludge per million gallons.

Composition of Sludge.

Nitrogen Content of Sludge.

The most important constituent of activated sludge is its nitrogen, and we have therefore made several series of determinations of the increase in the nitrogen content during the building up of activated sludge. Three series of determinations during the building up of sludge in tank C have been made.

The first series was collected from tank C during the period of October 4 to November 4. The sewage was changed three times a day for the first three weeks, with five hours' aeration of sludge alone; after that four changes per day were made. Thirteen samples of sludge were taken at suitable intervals. The sludge was filtered on a Büchner funnel, dried on the steam bath, and the amount of nitrogen determined. (Table XI).

The average time of aeration and amount of air are computed from the beginning of operation up to the collection of sludge 1, from the collection of sludge 1 up to the collection of sludge 2, etc.

TABLE XI

VARIATIONS IN NITROGEN CONTENT OF SLUDGE

| No. of Sludge | Collected | Days after start | Changed times | Av. air per treatment cu. ft. per 100 gal. sewage | Av. time of aeration hours | av. stability of effluents | %N in sludge |
|---|---|---|---|---|---|---|---|
| 1 | Oct. 4 | 0 | 1 | 750 | 4.0 | 0 | 3.6 |
| 2 | Oct. 5 | 1 | 4 | 520 | 4.5 | 5 | 4.4 |
| 3 | Oct. 6 | 2 | 7 | 380 | 4.5 | 8 | 4.2 |
| 4 | Oct. 7 | 3 | 10 | 630 | 4.5 | 10 | 5.3 |
| 5 | Oct. 8 | 4 | 13 | 510 | 4.8 | 15 | 4.9 |
| 6 | Oct.11 | 7 | 18 | 610 | 5.7 | 7 | 5.2 |
| 7 | Oct.13 | 9 | 24 | 660 | 4.6 | 13 | 4.8 |
| 8 | Oct.19 | 15 | 36 | 920 | 4.8 | 54 | 5.2 |
| 9 | Oct.25 | 21 | 53 | 1340 | 5.5 | 90 | 3.9 |
| 10 | Oct.27 | 23 | 61 | 1070 | 4.6 | 100 | 4.1 |
| 11 | Oct.28 | 24 | 65 | 690 | 4.5 | 96 | 4.1 |
| 12 | Nov. 2 | 29 | 82 | 1080 | 5.6 | 100 | 4.0 |
| 13 | Nov. 5 | 32 | 89 | 1280 | 5.6 | 99 | 4.1 |
| Average, excluding first day....... | | | | 800 | 4.9 | --- | 4.5 |

Interesting features are the high nitrogen (3.6%) in the sludge after one aeration, the rapidity with which the nitrogen content of the sludge increases, reaching its maximum, 5.3%, in three days, and the variations in the nitrogen content. Simultaneous with the decrease in nitrogen in sludge 9 there was a considerable increase in the time of aeration and in the amount of air which had been applied.

This suggests that the nitrogen content of the sludge is affected by the amount of aeration; that long aeration and over-treatment decreases the per centage of nitrogen present as well as the amount of sludge.

The second series was collected from tank C from January 6 to 25. During this test the sewage was changed 57 times, usually four times a day. From the seventh day, January 13, until 8 a. m. on the tenth day, January 17, no sewage was added, since the sewage had backed up in the sewer to such an extent that it could not be opened to clean out the clogged intake pipe. During this time the sludge was aerated alone.

Determinations of ammonia, nitrite and nitrate nitrogen and suspended matter were made on each raw sewage and effluent.

The nitrogen values of the sludge, collected at intervals show the same characteristics (see Table XII) as are shown by the first series, with the exception that the decrease in nitrogen on prolonged aeration is not so marked.

The third series was collected from tank C from March 9 to 23. The analyses included determinations of ammonia nitrogen, nitrite and nitrate nitrogen, stability, suspended matter, and

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TABLE XII

VARIATIONS IN NITROGEN CONTENT OF SLUDGE

| No. of sludge | Collected | Days after start | Changed times | Av. air per treatment cu.ft. per 400 gal. sewage. | Time of aeration, hours | % N in sludge | Remarks |
|---|---|---|---|---|---|---|---|
| | 1916 | | | | | | |
| 1 | Jan. 6 | 6hrs. | 1 | 890 | 5.5 | 3.40 | Very much |
| 2 | " 7 | 1 | 5 | 580 | 4.4 | 3.80 | Rain, dilute sewages |
| 3 | " 8 | 2 | 8 | 370 | 5.8 | 4.20 | |
| 4 | " 10 | 4 | 14 | 700 | 6.8 | 4.60 | |
| 5 | " 12 | 6 | 21 | 540 | 5.1 | 4.70 | |
| 6 | " 13 | 7 | 25 | 620 | 4.5 | 4.90 | |
| 7 | " 17* | 10 3/4 | 28 | 500 | 5.0 | 4.60 | *Sludge alone aerated for 74 hours before this sample was taken. |
| 8 | " 17 | 11 | 29 | 630 | 5.0 | 4.90 | |
| 9 | " 18 | 12 | 33 | 1010 | 4.5 | 4.90 | |
| 10 | " 19 | 13 | 37 | 570 | 4.5 | 4.80 | |
| 11 | " 20 | 14 | 41 | 520 | 4.5 | 5.10 | |
| 12 | " 21 | 15 | 45 | 460 | 4.5 | 4.90 | |
| Average, excluding first day....... | | | | 590 | 5.1 | 4.6 | |

the total organic nitrogen of the raw and filtered sewage. Sludge was collected and analyzed as before with additional determinations of phosphorus ($P_2O_5$) and carbon (C). Carbon was determined by fusion of the sample in a bomb with sodium peroxide, thus converting all carbon into carbonate. The fusion was dissolved in water, carbon dioxide was liberated by HCl, and measured in the Parr apparatus. Total carbon was calculated from the data thus obtained. (see Table XIII).

The same rapid increase in nitrogen in the first few days is very apparent. The effect of long aeration is shown more markedly. The nitrogen content was reduced from 5.7 in Sludge 7 to 4.9 in Sludge 8.

Recapitulation.

1. After 48 hours the nitrogen content of the first set of sludges averaged 4.5 %. An average of 800 cubic feet of air and 4.9 hours aeration was used during each aeration period. The strength of the sewage treated was normal.

2. After 48 hours the nitrogen of the second set of sludges averaged 4.6 %. An average of 590 cubic feet of air and 5.1 hours aeration was used. The raw sewage applied was very dilute, and considerable grit was mixed with the sewage.

3. After 48 hours the nitrogen of the third set of sludges averaged 5.1 %. An average raw sewage was treated with an average amount of air, (700 cubic feet) and an average period of aeration (4.9 hours).

Conclusions.

1. Under normal conditions, 5.1 % nitrogen is obtained

## TABLE XIII.

## ANALYSES OF SLUDGES.

| No. of sludge | Collected | days after start | Changed, times | Av. air per treatment cu.ft. per 400 gal. sewage | Av. time of aeration hours. | % N in sludge | % C in sludge | Ratio C:N | % $P_2O_5$ in sludge |
|---|---|---|---|---|---|---|---|---|---|
| 1 | March 9 | 5 hrs. | 1 | 460 | 5.0 | 2.94 | 44.2 | 15.0 | 1.70 |
| 2 | " 10 | 1 | 5 | 560 | 4.4 | 4.29 | 43.8 | 10.2 | 2.27 |
| 3 | " 13 | 4 | 14 | 690 | 6.5 | 4.41 | 42.4 | 9.6 | 2.66 |
| 4 | " 14 | 5 | 18 | 480 | 4.5 | 5.03 | 40.1 | 8.0 | 2.77 |
| 5 | " 15 | 6 | 22 | 640 | 4.5 | 5.09 | 40.0 | 7.9 | 3.32 |
| 6 | " 16 | 7 | 26 | 670 | 4.5 | 5.57 | 40.9 | 7.3 | 3.46 |
| 7 | " 17 | 8 | 30 | 800 | 4.5 | 5.66 | 40.4 | 7.1 | 3.33 |
| 8* | " 20 | 11 | 35 | 930 | 6.2 | 4.93 | 38.6 | 7,8 | 2.77 |
| 9 | " 21 | 12 | 39 | 620 | 4.5 | 5.30 | 39.0 | 7.3 | 2.88 |
| 10 | " 22 | 13 | 43 | 930 | 4.5 | 5.13 | --- | -- | 3.03 |
| 11 | " 23 | 14 | 47 | 850 | 4.5 | 5.52 | --- | -- | 3.11 |
| Average, excluding first day........ | | | | 700 | 4.9 | 5.10 | 41.0 | 8.0 | 2.96 |

*Sludge alone aerated.

considered worthless as fertilizers.

It is probable that the coarser suspended matter, which settles out to form such sludge, is low in nitrogen, while the finely divided, colloidal matter is relatively high in nitrogen. This colloidal matter is not removed from the first effluents, hence the sludge at the beginning of operation is low in nitrogen. As soon as more colloidal matter is removed, the sludge shows higher nitrogen values, reaching a maximum when all colloidal matter is retained in the sludge.

Lederer* has shown that the colloidal matter is more

*American Journal of Public Health, Feb., 1912, p. 97.

unstable than the "settleable solids", and this fact would seem to indicate that it is higher in nitrogen.

2. The high nitrogen value of activated sludge may be due to the fact as Adeney* has shown that oxidation of the organic

*Fifth Report, Royal Sewerage Commission, p. 11.

matter of sewage proceeds in two steps. The first step is the fermentation of carbonaceous substances; the second step is the oxidation of nitrogenous substances. The reaction

carbonaceous matter + oxygen = carbon dioxide

proceeds at a faster rate than

nitrogenous matter + oxygen = nitrate.

Eventually the latter reaction catches up with the former, at which point there is highest amount of nitrogen in the sludge.

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Further oxidation liquefies protein, and reduces the nitrogen content as noted.

Carbon Content of Sludge.

The carbon in the sludges obtained in series III during the first days (Table XIII) was higher than that in the last ones. The ratio of C:N decreased greatly. In the first sludge the ratio was 15:1. After a week's operation, the average ratio was 7.2:1. This supports the theory that the proportion of nitrogen present in the sludge is increased by a decrease in the carbon.

It is probable that the high nitrogen value of activated sludge is obtained by both the methods indicated--that is, by complete removal of suspended matter, and by the "burning out" of carbon.

Phosphorus Content of Sludge.

The value of activated sludge may depend to some extent on the phosphorus content. The phosphorus in a series of eleven sludges varies in the same manner as nitrogen. (see Table XIII). The same theories which account for the building up of nitrogen in the sludge are applicable to the building up of phosphorus.

Proportion of Suspended Solids Retained as Activated Sludge.

During the test from January 6 to 25 16.2 pounds of dry sludge were recovered from 22,200 gallons of sewage. The average quantity of suspended matter in the raw sewage was 104 parts per million. Since the effluent was passed through a 16 mesh screen it was approximately free from suspended matter. All the suspended matter of the raw sewage must have remained in the tank,

or must have been removed by liquefaction of the sludge.

If all remained 22,200 gallons of sewage containing 104 parts per million suspended matter should have given 19.1 pounds of dry material. Since only 16.2 pounds or 85 % were recovered, 2.9 pounds or 15% must have been liquefied.

During the test from March 9 to 23, 13.6 pounds of dry sludge were recovered from 18,400 gallons of sewage.

The average quantity of suspended matter in this sewage was 121 parts per million. 18,400 gallons of sewage containing 121 parts per million suspended matter should have given 18.4 pounds of dry material. 13,6 pounds is a recovery of 74 %.

Conclusions.

These very meager data indicate that from 75 to 85 % of the suspended matter in the sewage can be recovered in the form of activated sludge.

It is interesting to compare this removal of suspended solids with that obtained by plain sedimentation. It has been found that a certain amount of the finely divided suspended matter of sewage cannot be removed even with prolonged sedimentation. This suspended matter is in a colloidal state, forming a hydrogel which is not precipitated by plain sedimentation.

Fuller* states that only 70 % of the suspended matter in the sewage of Columbus, Ohio, could be removed by plain sedimentation. The remaining 30 % passes off in the effluent and

*Fuller, Sewage Disposal, p. 394.

can only be removed by special treatment.

The removal of this finely divided suspended matter is one of the most advantageous features of the activated sludge process. The effluents are practically free from colloidal matter and nearly 100 % of the suspended solids is removed.

Activated sludge has been found valuable as a fertilizer.* Because of its high nitrogen and phosphorus values, it

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*Bartow and Hatfield, The Value of Activated Sludge as a Fertilizer, 1915, J. Ind. & Eng. Chem.

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is undoubtedly worth recovering. This fact gives a different character to the sludge question. In former processes, a small amount of sludge was desired and all possible means for liquefying sludge were used. In the activated sludge process all possible means should be used to recover as much suspended matter as possible. A recovery of 75 to 85 % is desirable and even higher yields may be possible.

<u>De-watering Sludge</u>.

The sludge separates from the water with a sharp line of demarcation. As it is taken from the tanks it has the appearance of a flocculent precipitate of ferrous-ferric hydroxide. It usually contains 98 to 99 % water.

Upon standing it settles somewhat, but after three or four hours it becomes filled with bubbles of gas from anaerobic decomposition, which cause the sludge to rise to the surface. In this condition it contains 97 to 98 % water and appears more like a hydrogel. Upon further standing it becomes septic and very colloidal.

For de-watering the sludge a simple sludge drying bed of sand and gravel was constructed as described on page 51. In warm, dry weather the bed gave fairly satisfactory results. The sludge dried to a tough, leathery consistency, and had to be dried further on the steam bath before it could be ground. If a rain occurred while the sludge was on the bed, none of the water would filter through the partially dry sludge. The rain water had to be removed by decantation, or by evaporation.

In the winter it was impossible to dry any sludge on the bed. Alternate freezing and thawing prevented drainage through the sand, and snow and rain kept the sludge wet.

In order to obtain a sludge in marketable condition some degree of heat drying must be used. The amount of fuel required for drying varies with the amount of water contained in the sludge. Grossman* has compiled formulae and tables showing the amount of water that must be evaporated from sludges containing varying amounts of water and assuming that one pound of coal will evaporate six pounds of water from sludge, and that the cost of coal is $1.25 per ton, he has calculated the cost of coal for such evaporation.

*J. Soc. Chem. Ind. XXXIV, No. 11, p, 589.

If $x$ is the percentage of solid matter and $y$ the amount of water in tons to be evaporated to yield one ton of dry sludge,

$$y = \frac{100}{x} - 1$$

If m is the price of coal in dollars per ton, n =

pounds of water evaporated per ton of coal, and z = cost of evaporating sludge containing x% of solid matter to dryness,

$$z = \frac{m}{n}\left(\frac{100}{x} - 1\right)$$

The cost of evaporating water from sludges containing from 5 to 50 per cent of solid matter has been calculated. (see Table XIV)

It will not pay to reduce the sludge by purely mechanical means to less than 70 % water, if it must be subsequently dried by heat. A sludge with 80 % water could be economically dried and between 70 % and 80 % satisfactory results can be obtained.

Precipitation of Sludge.

In order to reduce the water in the sludge to such an extent that drying by heat could be used, experiments with several precipitating agents and a freah sludge containing 98 % water were carried out. (See Table XV.)

Sodium phosphate is apparently a very good precipitant but the results obtained with 5 grains per gallon even after 24 hours settling do not warrant its use.

A 98 % sludge contains 2 grams of solids and 98 grams of water. If the volume of water in the sludge is reduced 45 % by the precipitant there will be 2 grams of solids in the remaining 55 grams of sludge, or 3.6 grams of solids in 100 grams of sludge and the water in the sludge has only been reduced from 98 % to 96.4 %.

It is apparently futile to attempt to reduce the water content of sludge by precipitants. Precipitants may alter the physical character of sludge to such an extent that it may be

TABLE XIV

THE DRYING OF SEWAGE SLUDGE.

| x<br>% of solid matter | y<br>tons of water to be evaporated to produce 1 ton of dry sludge. | x<br>cost of drying coal = $1.25 per ton 1 lb. coal will evaporate 6 lbs. water. |
|---|---|---|
| 5 | 19 | $3.96 |
| 10 | 9 | 1.88 |
| 15 | 5.7 | 1.17 |
| 20 | 4 | .84 |
| 25 | 3 | .63 |
| 30 | 2.3 | .49 |
| 35 | 1.9 | .39 |
| 40 | 1.5 | .31 |
| 45 | 1.2 | .25 |
| 50 | 1.0 | .21 |

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TABLE XV.

PRECIPITATION OF ACTIVATED SLUDGE.

| Precipitant | Percent reduction in volume of sludge. | | | |
|---|---|---|---|---|
| | 0 hours settling | 2 hours | 3 hours | 4 hours |
| Sodium Phosphate $Na_3PO_4$ 5 grains per gallon | 0 | 15 | 20 | 45 |
| Lime and Iron $CaO + FeSO_4$ 5 grains per gallon $FeSO_4$ | 0 | 15 | 18 | 44 |
| Lime $CaO$ 10 grains per gallon | 0 | 12 | 16 | 41 |
| Alum $Al_2(SO_4)_3$ 5 grains per gallon | 0 | 8 | 12 | 35 |
| Control | 0 | 6 | 10 | 26 |

filter-pressed or dried more easily. If this is possible precipitants must be chosen that would add something valuable to the dried sludge when used as a fertilizer.

Limestone and rock phosphate, substances which do not react with the substances dissolved in water to form a floc, added in the same manner had no noticeable clarifying or coagulating effect.

Filter-pressing Sludge.

Attempts were made to de-water the sludge by filter-pressing alone, and because of its cheapness, also because it de-odorized septic sludge, by filter-pressing the sludge after the addition of lime.

The smallest Sperry Filter Press was used. This was the usual hollow frame press, into which the sludge was fed from a drum under 70 pounds air pressure. Satisfactory results were not obtained.

February 17. 17,000 grams were treated with 20 grains per gallon of lime. After 4 hours at 70 pounds pressure no cake was formed. A slimy mass remained in the frame.

February 21. 8,000 grams of fresh sludge after being pressed 6 hours at 70 lbs. pressure, yielded only a very slimy cake.

February 22. 15,000 grams pressed for 6 hours at 70 lbs. gave a cake firm around the edges but slimy in the center. Average solids, 89.7%.

February 23. 16,000 grams were treated with 5 grams per liter of lime, and pressed for 5 hours at 70 lbs. No cake

was formed.

February 24. 15,000 grams were pressed for 5 hours at 70 lbs. without lime. No cake was formed.

It was practically impossible to obtain a good cake with or without lime because the filter-cloth became clogged by an impervious layer of sludge, and at 70 lbs. pressure no more water could be forced through it. Lime does not seem to change the character of the sludge so that it will not clog the filter-cloth.

Filtros plate filters.

Two 6 inch Filtros plates cemented into a frame have been lowered into the sludge and suction applied to an outlet between the plates. A very thin film of solid matter stuck to the plates, and after it had been formed no water could be drawn through it. This device,intended to simulate the action of a large-scale device called the "Robacher wheel", gave only unsatisfactory results.

Centrifuges.

Two small centrifuges, one of the low speed,basket type, the other of the high-speed,bottle type, have been available for experimental works.

The basket of the low-speed machine was 8 inches in diameter and 6 inches deep, and the periphery was perforated with numerous 1/16 inch holes. The machine was lined with a strip of muslin cloth covering the holes, 3,500 grams of 98% sludge were added;after 15 minutes, 700 grams of 91% sludge were obtained.

The effluent was very dark colored, but the cake was firm and uniform in consistency.

With the high-speed,bottle-type machine the moisture was reduced from 98% to 92% in three minutes. The supernatant liquid was very clear.

Considering the crudeness of the basket-type centrifuge used, the results obtained were promising, and such an apparatus, in a more efficient form, is a possibility for the drying of sludge down to 80% water. In order to be economical, an automatic arrangement for removing the cake must be provided. Such machines are not made in this country, but have been in use in Germany for some years.

The most successful apparatus of this type is the Schafer-ter Meer centrifuge* built by ter Meer at Hanover

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*Mit.Konig.Prufung. fur Wasserver, und Abwasseversorg. 10,(1908,) 174.

G. T. Hammond. Eng.News, 75, 17, 800.

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according to the design of Schafer, city engineer of Frankfort. This machine consists of a revolving drum, mounted on a hollow vertical axis and surrounded by an outer casing.

The wet sludge enters the center of the revolving hollow axis through an overhead inlet pipe while the machine is in motion. Six radial compartments are attached to the axis, and the inner and outer peripheries of these compartments are closed and opened by slide valves controlled by oil under pressure. On the sides of the compartments are numerous slots 10 by .5 mm. Each cell holds 3 liters.

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The operation is intermittent. Sludge is admitted from the hollow shaft. The heavier particles are thrown against the outer part of the cells, while the water escapes through the slots in the sides. The cells are filled with sludge in 2 to 3 minutes. The inner valves are then closed automatically and after a number of revolutions of the drum the outer valves are opened. The dried sludge is thrown from the cells and falls down onto a belt conveyor. A star-shaped scraper mechanically cleans the sides of the cells after the sludge has been thrown out. This entire cycle is repeated, once in 2-1/2 to 3-1/2 minutes, a dilute sludge requiring a longer period than a more concentrated one. The drum makes 750 revolutions per minute.

The apparatus will treat approximately 4 cubic yards, or 6,800 lbs. of a 92% sludge per hour. The discharged sludge averages 60- 70% water, and is crumbly and odorless, except in very warm weather, when a slight odor is produced. The effluent is turbid, and must be passed through sedimentation basins in order to give a clear liquid.

This machine uses 6.4 kilowatts, and the cost of producing 1 ton of dried material (60 - 70%) water is $.36, this figure including depreciation. Each machine costs $5,500.

Such machines may be applicable to the drying of activated sludge, but they must be tried on a large scale.

Conclusions.

1. Unprotected sludge beds are not satisfactory for drying activated sludge in winter or in rainy weather.

2. A filter press with 70 lbs. pressure did not give

a satisfactory cake even with the addition of lime. The sludge is so gelatinous that it clogs the filter-cloths very rapidly.

3. Filtros plate suction filters were not found satisfactory because a thin impervious layer of sludge formed on the plates, which completely prevented the water from being drawn through.

4. Centrifugal machines gave promising results on a small scale.

The economic success of the activated sludge process depends to a great extent on the solution of the problem of drying the sludge cheaply and easily. Although the disposal of the sludge has been the unsolved problem of present-day methods of sewage disposal, it is very likely that an effective method of de-watering activated sludge will be found, because its value as a fertilizer offers an incentive for recovering it that is much greater than for recovering other kinds of sewage sludge. With nitrogen at 20 cents per lb., a sludge containing 5% nitrogen should be worth $20.00 a ton if the nitrogen is in an available form. Experiments by Bartow and Hatfield*

*Bartow-Hatfield, The Fertilizing Value of Activated Sludge. Eng. & Contracting, XLIV, 22, 435.

have shown that the nitrogen is very available and that activated sludge may be considered at least as a medium-grade fertilizer. Considering this fact, it should not be considered in the same category as septic tank sludge, Imhoff tank sludge and other sewage sludges, but should be classed with much higher grade materials such as fish-scrap, tankage, dried blood, etc. If some

satisfactory method of reducing the water content to 70 - 80% is developed, final drying may certainly be carried out by some form of hot-air dryer.

Costs.

The cost of constructing and operating activated sludge plants have not been considered in this investigation, which has been confined more or less exclusively to the phases of chemical and biological interest and significance. The data which have been presented on such features as the building up of sludge, the amount of diffusion area required, the amount of air necessary, and the amount of nitrogen in the sludge, are of interest and value to the designer and operator of large-scale plants. Cost data must be secured by operation on a large scale in order that it may have the proper weight and significance.

A continuous-flow plant, having an estimated capacity of 200,000 gallons per day, has been built by the State Water Survey for the purpose of securing such data.

A plant with an estimated capacity of 2,000,000 gallons per day has been constructed at Milwaukee, Wis., and operated during the winter of 1915-16*.

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*Eng. Record, 72, 16, 481.

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At Cleveland, Ohio, a plant with an estimated capacity of 1,000,000 gallons per day was put into operation the latter part of January, 1916**.

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**Eng. News. 75, 17, 800.

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Operation of these plants will determine whether the activated sludge process is a success financially.

## SUMMARY

1. In the aeration of sewage there is almost quantitative oxidation of ammonia nitrogen to nitrite nitrogen followed by oxidation to nitrate nitrogen. From ten to twenty days are required. In the aeration of sewage in contact with activated sludge ammonia nitrogen is oxidized to nitrate nitrogen in from four to five hours. Nitrite nitrogen is evidently oxidized to nitrate nitrogen almost as fast as it is formed.

2. Satisfactory activated sludge can be obtained with six hour aeration periods without complete nitrification from the beginning of the operation.

3. In a small tank the equivalent of 1,300 lbs. of dry sludge was obtained per million gallons of a strong sewage. In larger tanks from 740 to 1,150 lbs. of dry sludge were obtained per million gallons of average sewage.

4. With 25% of sludge weak sewage was well nitrified in four hours with one cubic foot of air per gallon of sewage. Normal sewage required 4 to 5 hours aeration and 1.3 cubic feet of air per gallon of sewage. Strong sewage required more than 5 hours aeration and more than 1.5 cubic foot of air per gallon of sewage.

5. Better results were obtained when one-third of the floor surface was covered with porous plates than when all, or one-ninth of the floor surface was covered.

6. The nitrogen in the sludge increases by from .4 to 1.5% of nitrogen daily until an average of 5.1% of nitrogen is

obtained. Excessive aeration decreases the total quantity of the sludge and the percent of nitrogen in the sludge.

7. The content of phosphorus pentoxide ($P_2O_5$) varies in the same way as nitrogen reaching an average of about 3%.

8. As yet we have found it practically impossible to obtain a solid cake by filter pressing the activated sludge. Centrifuges used on a small scale have given promising results.

# BIOGRAPHICAL

The writer was born in Beardstown, Illinois, and secured his early education in the public schools of that city. He attended the University of Illinois from 1907-1912, and secured the degree Bachelor of Science in Chemistry in 1912. From 1912-1916 he has been Assistant Chemist in the Illinois State Water Survey. In 1914 he secured the degree of Master of Science from the University of Illinois. He is a member of Phi Lambda Upsilon and Sigma Xi.